Optimizing the number and location of public litter bins using Geographic Information Systems

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Abstract

The distance that users need to walk to public litter bins is a strong predictor of littering behaviour. However, there is limited research that combines the spatial allocation of bins and users' preferences on access to litter bins. The goal of my thesis was to optimize the number and location of public litter bins by assessing the distance users are willing to walk to bins and incorporating these distances in a network analysis in Geographic Information Systems (GIS). Macquarie University, Sydney, New South Wales was the case study area. 200 face-to-face surveys were conducted to ascertain user opinion on the distances they were willing to walk to bins. I used the survey outputs to develop 56 scenarios that provide managers of waste with a range of options to meet demand and user preferences, including allocating additional bins to the current distribution, redistributing bins and reducing the number of bins. I found that most users were willing to walk between 38–80 metres. Due to the heterogeneity of population distribution, I found that the most appropriate network analysis tools were maximize attendance and target market share. The approach I developed could be used to optimize the number and location of public litter bins at other locations of similar scale.

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Equally, my dissertation would carry no value for me without the patience and support from my husband Bikalpa Gautam, the blessings of my parents and care from other family members.

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Declaration

I hereby declare that this thesis has not been previously submitted to any other institution or university for a higher degree. Except where otherwise acknowledged, this thesis is comprised entirely of my own work. In addition, Ethics Committee approval (5201500370) has been obtained for this study.

Nirodha Neupane

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Chapter 1: Introduction

Solid waste causes social, economic and environmental problems if not effectively managed. These problems include contamination causing environmental and human health issues, climate change (EPA, 2002) and financial costs associated with remediation (Morrissey and Browne, 2004). Planning and implementation of an inclusive program of waste management is essential to reduce these potential problems.

Litter is a subdivision of solid waste management and focuses on the management of waste by individuals in public spaces. Litter ranges from small objects such as cigarette butts or plastic food wrappers, through to larger items such as abandoned furniture or tyres. Litter in managed by organisations and local or regional governments at multiple sites and scales, including individual office buildings (organization scale), business park (enterprise scale) or entire municipalities (council scale). Litter is a pervasive environmental, social and public health issue (Weaver, 2015) and waste management is challenged by maintaining effort at various levels of the waste lifecycle, including waste collection, recycling, and transportation of waste to landfill and litter minimization.

Minimizing the amount of litter leads to improved safety, good health and protection of the natural environment (NSW, 2011). In order to minimize litter, we need to understand how and why litter is generated. In 2008, the Beverage Industry Environment Council, Australia published a survey regarding littering behaviour (NEPC, 2008). The survey found that the most common reason for littering was ‘no bins nearby’ (NEPC, 2008). Research is therefore needed to understand how far people are willing to walk to a bin, and their perception on the distribution of litter bins in a specific area. In this context, one key analytical approach is optimization which provides a mechanism to distribute and allocate bins to minimize costs but also maintain user’s preferences and service capacity.

Optimizing the location of bins using Geographic Information Systems (GIS)

Geographic Information Systems (GIS) are an integrated collection of hardware, software, data and liveware which has the capacity of design, cartography, database management and remote sensing (Maguire, 1991). In the context of planning and solid waste management, GIS has been used for mapping, creating databases and spatial analysis. Key factors to consider when optimizing the location and number of litter bins are the cost of installation, maintenance cost, estimation of the waste generation and their on-site storage capacity (Chang and Pires, 2015). Optimization modelling of waste management using GIS has focused on: vehicular routing (Shih and Lin 1999; Kyessi and Mwakalinga 2009; Kim *et al.* 2006), minimizing operation costs and pollutant emissions (Zsigraiova, *et al.* 2013 and Tavares, *et al.* 2009), optimizing waste collection (Vijay *et al.* 2007, Anghinolfi *et al.* 2013) and selecting landfill sites (Kao *et al.* 1997; Muttiah *et al.* 1996; Leao *et al.* 2001). Aremu and Sule (2012) also assessed the aftermath of application of optimization to identify if the output was environmentally, socially and economically viable. Several models are proposed on the placement of litter bins that focus on cost minimization of waste collection, maximizing coverage and accessibility to the public and maximizing efficiency for waste collectors (Chalkias and Lasaridi, 2009; Alvarez *et al.* 2008; Kao and Lin, 2002). Some studies have also used mathematical models to help decision makers to locate public use bins (Ghiani *et al.*2014; Bautista and Pereira, 2006).

GIS has proven to be an extensively accepted method of locating facilities, particularly through network analysis (Kao and Lin, 2002; Aremu, *et al.* 2011). Network analysis is used to find the best single or multiple locations which are capable of meeting maximum utility. It is also used to solve spatial problems such as finding the most efficient route, travel directions and closest facility and defining service areas based on travel time (ESRI, 2011). The location of public facilities like litter bins, emergency services or hospitals has been modelled using GIS (Kao and Lin, 2002; Aremu, *et al.* 2011). Network analysis functions such as location set covering (LSC), maximum covering location (MCL) and shortest service location (SSL) were used for allocating litter bins in a municipality in order to select the optimum number of kerbside pickup locations for cost efficiency and service quality (Kao and Lin, 2002). Network analysis has also been used to reallocate bins to different areas in order to optimize collection and to reduce collection time and man-effort (Chalkias and Lasaridi, 2009). However, there is limited research that incorporates user's perspective in the optimization of litter bins (Higgs, 2006).

As noted above, optimization is a process of allocating the least number of facilities to cover a defined area at lowest cost (Murray and Wei, 2013). Optimization is an essential process because municipalities and local authorities are under constant pressure to provide effective services at minimal cost (Chalkias and Lasaridi, 2009). Not having a facility at an optimal distance for users to access, reduces its usage and value. For example, facilities like hospitals, police stations, or schools should be located where the maximum number of people can utilize them (Kao and Lin, 2002). However, the capacity of facilities also needs to be considered. If a facility has lower capacity than the amount of population demand for the facility, it becomes necessary to install additional capacity. Therefore, optimization of the number and location of litter bin facilities needs to consider user's preferences, population demand and the capacity of litter bins in a defined area (Chalkias and Lasaridi, 2009; Ghose, *et al.* 2006).

Understanding user's perception in terms of how far a facility should be is essential to maximize the utility of the facility (Taylor, 2004). A facility will not be used unless it is accessible. In addition, littering behaviour also depends upon how users feel about place and their sense of ownership. For example, a well-managed landscape sends a message of safety, and alternatively an unmanaged area indicates an unsafe community (EPA, 2000). Waste and consumption practices are multi-dimensional and incorporate public feelings in management gives a practical perspective (O'Connell, 2011). However, research to date has failed to take into account user's perspective and link this to modelling bin location to optimize the number and location of bins.

Previous studies on litter bins have focused at the broad scale of municipalities (Kao and Lin, 2002; Chalkias and Lasaridi, 2009; Aremu, *et al.* 2011). To date, there has been limited research at the enterprise scale. Enterprise scale is medium-sized businesses that employ more than 200 permanent staff (ABS, 2002). This includes entities such as business parks, universities and hospitals. In such organisations, waste is managed privately and not by municipalities or councils (Worthington and Dollery, 2001).

Based on my literature review (Chapter 2), I identified key factors influencing the optimization of litter bins at an enterprise scale (Figure 1.1). Drawing together these key factors, this thesis seeks to optimize the number and location of public litter bins at an enterprise scale by assessing the distance users are willing to walk to bins and incorporating these distances in a network analysis in GIS. To date, the optimization of litter bins in GIS has not incorporated user's preferences or been conducted at an enterprise scale. This research will therefore be novel in both of these aspects.

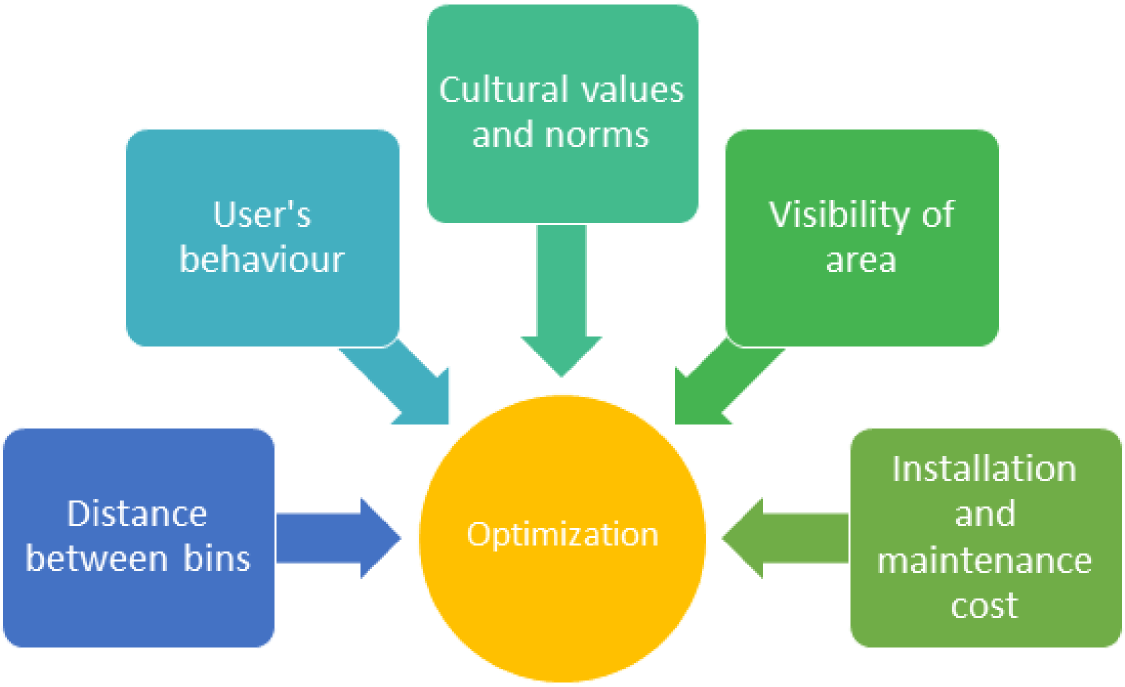

Figure 1.1: Key factors influencing optimization of litter bins at an enterprise scale.

Thesis objectives

The distance that users need to walk to public litter bins is a strong predictor of littering behaviour (Liu and Shibley, 2004). The goal of my research is to optimize the location of public litter bins at an enterprise scale to minimize litter incidences. Specifically, my research objectives are to:

1. Map the distribution of public litter bins and model population density;
2. Ascertain the willingness and attitude of staff and students to walk to litter bins; and
3. Undertake an optimization analysis combining the outputs of objectives (1) and (2) to develop a range of bin location options in the study area.

In order to achieve my goal to optimize the location of litter bins at an enterprise scale, I first needed to map the current distribution of bins and model population density in the study area (Objective 1). A survey with students and staff of Macquarie University was conducted to produce both quantitative and qualitative responses to inform an assessment of willingness and attitude towards walking to litter bins (Objective 2). The outputs of Objective 1 and Objective 2 were then combined in a network analysis to develop maps of new distributions of litter bins using multiple scenarios (Objective 3) (Figure 1.2).

The outputs of my thesis include an optimized design of the number and location of bins within Macquarie University that incorporates staff and student perspectives. My thesis informs the management of public litter bins at Macquarie University by providing options for bin placement at the lowest cost, to provide enough facilities and reducing littering incidents. I provide advice on how the outputs of this research can be replicated in other universities, offices and businesses and to wider study area to achieve a similar target.

The thesis is structured as follows. The key literature in the field is reviewed in Chapter 2, which mainly considers the application of GIS in the field of waste management and optimization models. In addition, I also review literature on behaviour and attitude towards litter and identify research gaps. Chapter 3 presents the methods of this study and explains the process of data collection, preparation and analysis. Chapter 4 presents the results and Chapter 5 provides a discussion of the results and presents the outcomes of my thesis.

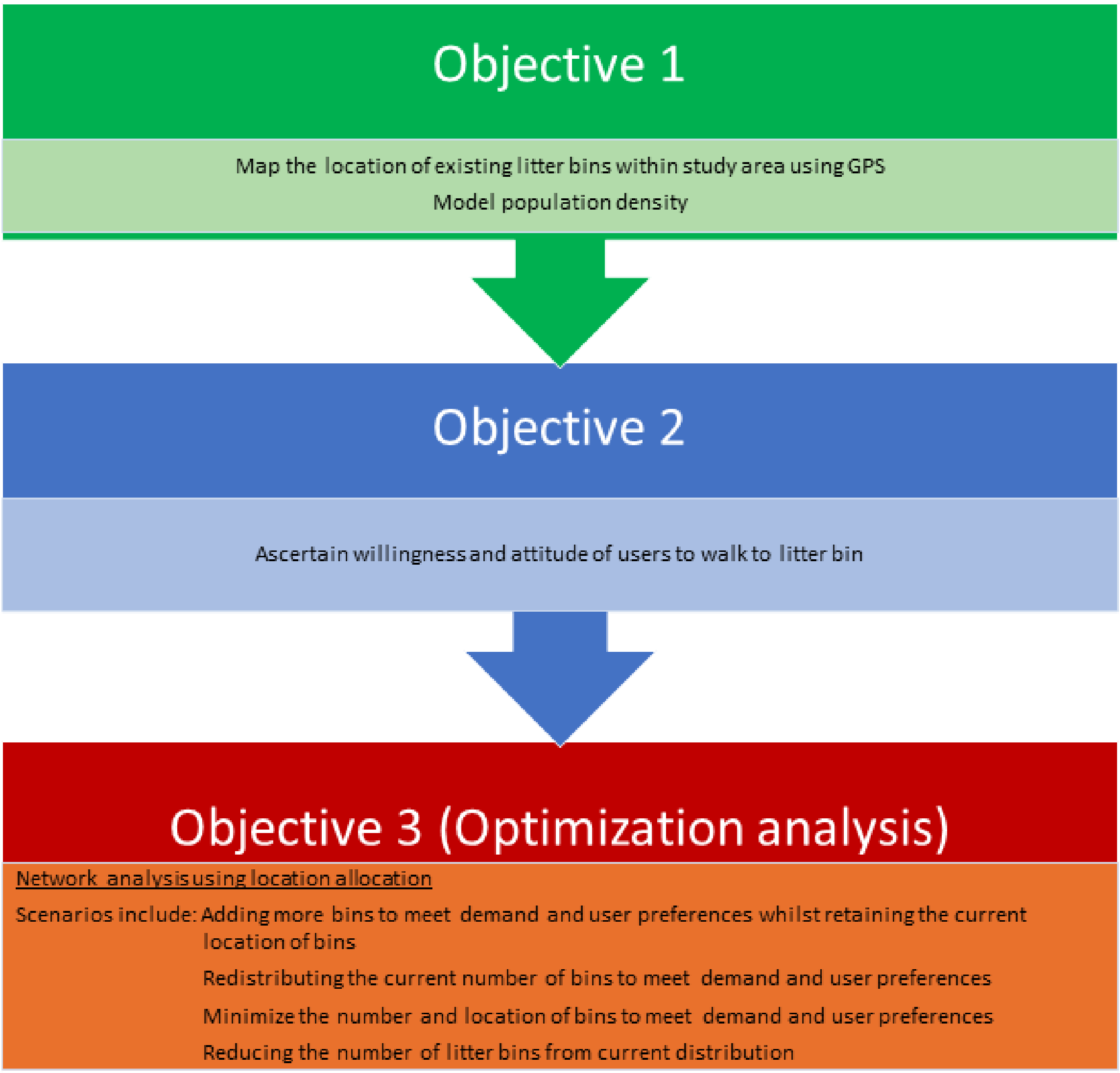

Figure 1.2: Flow chart of research objectives and their associated methodology.

Chapter 2: Literature Review

In this chapter, I will focus on the application of GIS in the field of waste management and optimization. I begin by presenting a general background on waste management and litter issues. Second, I consider the relationship between people's attitude and behaviour and litter management. I then study how GIS is applied in waste related research, specifically optimization and network analysis. Finally, I identify the knowledge gaps in this field of research.

Waste management and litter

Waste and its management has become complex in recent years, involving many new technologies and integrated strategies. Increasing volumes of waste, new types of recyclable waste resources, and the urgent need for people to behave according to prevalent waste management systems are key factors which make it challenging to achieve sustainable waste management. In addition, various stages of waste processing have been identified from creation of waste, to collection, transfer, recycling and disposal. Therefore, careful waste management is required at every stage or sector, which has resulted in the concept of Integrated Waste Management (Figure 2.1).

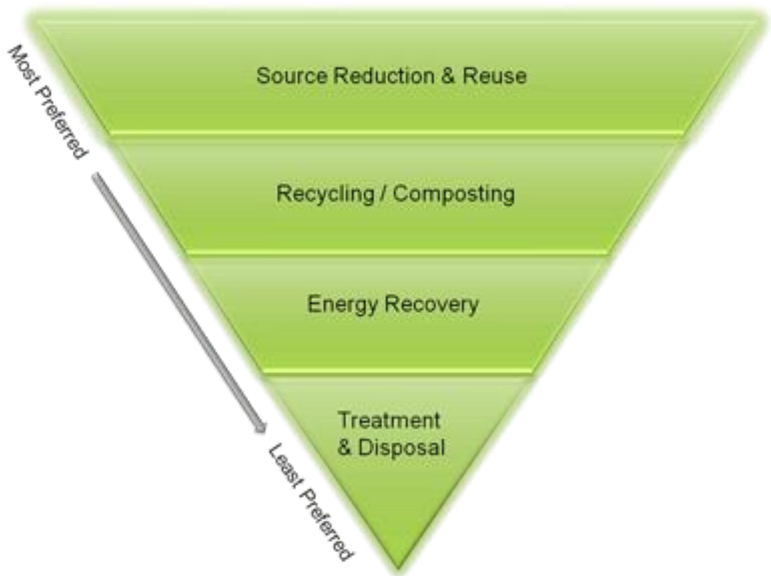

Figure 2.1: Integrated Waste Management Hierarchy (EPA, 2015)

Research has focused on several aspects of waste management, including: efficiency of recycling (Blengini, *et al*. 2012), people's attitude towards recycling (Knussen, *et al*. 2004), life cycle assessment (Slagstad and Brattebo, 2012), and community participation (Chakrabarti, *et al*. 2009). Other studies compare different alternatives of managing waste such as recycling, incineration, landfill, etc. to understand their environmental and economic viability (Schmidt, *et al*. 2007; Villanueva and Wenzel, 2007).

A major factor that has limited the uptake of sustainable waste management policies is individual behaviour. Individuals along with communities, firms and the public sector, are required to achieve long term changes. Tudor *et al*. (2007) assessed the link between behaviour and intention of individuals within a health organisation. They found that the key factors linking behaviour and intention are belief systems and attitudes of employees. In other words, if employees believed that recycling was important to manage waste, then they would transform their intended behaviour to action. To understand how litter has been perceived in literature and people's behaviour towards it, I now turn to focus specifically on the issue of litter.

One of the key sectors in waste management is public litter. Litter is defined as the small amount of waste which is disposed of carelessly and incorrectly (Hansmann and Scholz, 2003). Items can be as small as cigarette butts or sweet wrappers, to bulky items like unwanted furniture and tyres. These can be thrown away in many ways: actively, unknowingly, passively or sometimes by accident. Litter can also be discarded in many kinds of spaces including: parks, roads, stores, takeaways, business parks, and transport stations.

There have been various attempts to control litter in open spaces. These include: bringing policies and laws in place, modifying people's behaviour through campaigns, and doing research to find attitude of litterers (Hansmann and Scholz, 2003; Ong et. al. 2012). In one of the earliest studies on litter, researchers worked with children in two neighbourhood theatres to encourage them to pick up their litter and dispose of it responsibly. This resulted in the reduction of over 90% of litter in the area (Burgess, *et al.* 1971). This study was considered encouraging during the 1970's as there was lack of attention to litter issues at that time. Another litter related study was conducted by Finnie (1973) who explored the design of litter bins in relation to concerns about how littering could be reduced. This was also performed during a period when street sweeping and litter collection was not considered an everyday activity, but rather was only done when litter started piling up in open spaces or streets.

There is a direct cost associated with litter as it requires someone else to clean it up (Anand, 2000). If not collected regularly, it causes significant environmental damage (fire risks, impact to wild animals), health risks or social degradation (increase in crime or vandalism). However, if a space is kept clean and litter-free, the local community is able to enjoy the healthy environment and keep positivity alive (Anand, 2000). Some studies have claimed that there are multiple factors which need to be combined to reduce littering behaviour (Hansmann and Scholz, 2003; Ong and Sovacool 2012; Eastman *et al*. 2013). First is having policies and laws in place, along with proper infrastructure, so that space is created for people that encourages them to behave in a certain way. Second, effective education should be provided; this may be community education, active awareness in school or posters and banners as infrastructural intervention to remind the community what is required. Giving rewards for not littering is another way of encouraging litter-free environments.

Behaviour and attitude towards litter

Research suggests that it is carelessness, laziness or inconvenience that contributes to most littering behaviour (Al-Khatib, *et al*. 2009). Activities such as positive messages, rewards or taxes on littering behaviour, indirect impact of littering activities such as plastic bag bans, etc. help to reduce litter (Garces, *et al.* 2002). It has also been demonstrated that that there is higher probability of littering in places where there is already litter present, whereas clean areas remain mostly litter free (Cialdini and Reno *et al*. 1990). Similarly when people observe any violation of norm, it tends to weaken the norm and social validity (Krauss, *et al.* 1976).

There is a large pool of literature that examines relationships between existing waste management systems and users' attitudes along with the extent of participation in minimisation and recycling. Increasing volumes of waste and levels of awareness among people are key concerns for managers planning for sustainable waste management (Tonglet, *et al.* 2004). Factors that encourage a consumer's positive attitude towards waste management and increased participation include: social and family influence, prompts and information about recycling, and minimisation programs. Monetary rewards help users to exercise desirable recycling practices (Garces, *et al.* 2002). It is therefore clear that awareness is an important element in assisting people to become pro-environmental. Schulz, *et al.* (2013) also shows that littering behaviour was highly (85%) dependent upon individual-level variables such as age, gender, attitude and motivation. Age and availability of litter bins showed inverse relation to littering events whereas presence of existing litter has a direct relationship to littering.

Research has also explored behaviour and attitudes of people towards littering. These are typically interventional studies which involve raising awareness in some way or by focusing on new infrastructure such as litter bins. For example, a comparative study of litter behaviour between Singapore and Japan (Ong and Sovacool 2012) found that the institutions, organizations, and public norms help in maintaining the cleanliness of Singapore, where large amounts of money are spent on litter removal. On the other hand, volunteers play a bigger role in keeping the environment clean in Japan, where cleaning has an honourable value costing less to remove litter. Ong and Sovacool (2012) shows the importance of active learning in school and illustrats that when litter is considered to be valuable, then people are reluctant to discard it in the first place and are easily persuaded to pick it up if required. This proves that acceptability increases when people perceive that everyone has equal responsibility of managing litter and cleaning.

Hargreaves (2011) demonstrates that it is necessary to understand the culture, life style and behaviour of a community before intending to change their behaviour to be pro-environmental. In addition, detailed studies should be done on relationships between society and power and on how practices are reproduced or changed in the past. This means that a broad understanding of social life and change is required along with abandoning narrow models of individual behaviour to attain sustainability.

Similarly, Cialdini and Reno (1990) assessed the value of norms on littering events by individuals. They emphasize that researchers should separate two types of norms: injunctive norms (what most others approve/disapprove) and descriptive norms (what most others do) and conclud that cultural, situational and depositional factors influence one's norm and therefore littering behaviour. In addition, they also observe that least littering was observed in cleaner areas which supported norm focus predictions and where bins were visible.

Schulz, *et al.* (2013) also point out the importance of litter bins and their placement in public places. They find that having more litter bins reduces the littering rate; every new litter bin introduced in their study reduced litter in the study area by 1%. They also suggest that 'optical spacing' between litter bins should be considered along with convenience and accessibility to users. The authors added that spacing bins between 6.5 to 18 meters apart increased the amount of litter, whilst litter bins spacing less than ~ 7 meters apart showed the lowest rate of littering. Perry, *et al.* (2010) support this finding as they conclude that placement of bins in public space is a crucial element in managing litter.

Placing a litter bin in a relatively hidden area, such as near bushes and where people do not frequently walk, might promote misuse of bins. When there is no one around to judge people's activity, correlation between attitude and behaviour is reduced. Liu and Sibley (2004) assessed how visibility of a place impacted on littering behaviour and found that people behave differently when they are in public places. This is because people perceive uniformity in behaviour from group interactions or get cues from the physical environment they are in. Liu and Sibley (2004) emphasize attitudinal or structural interventions according to the visibility of the space. The research showed that correlation between attitude and behaviour is stronger for active litterers and structural intervention like litter bins has greater influence on behaviour for passive litterers only. Therefore, optimizing the number of bins in relation to behaviour is clearly significant.

A summary of papers on people's attitude and behaviour towards litter is provided in Table 2.1. I found that attributes such as social norms, culture, attitude-behaviour correlation, social demand, skill, and power, along with availability of infrastructure and its design, are equally central in achieving pro-environmental attitudes and litter-free environments. Having established behavioural effects and attitudes on litter, the following section presents an in-depth consideration on how litter analysis has taken place using GIS.

Application of GIS in waste research

GIS is an integrated system for creating, managing and analysing geographic data. It stores geographic data and attributes to enable the formulation and answering of questions regarding the interactions between multiple spatial data-sets (Sharholy *et al.* 2007). GIS was initially applied as a cartographic tool (Wood, 1992). In the following decades, GIS was increasingly used to analyse spatial data from numerous sources and across themes and scales. As computing power increased, GIS became a more affordable and easy-to-use system for displaying and analysing data.

Over the last 30 years, GIS applications, initiated with basic map layering, have advanced to combine qualitative and quantitative data (descriptive information) to permit investigation of various spatial relationships. Currently, GIS is used successfully in a wide variety of applications such as urban planning, health science, environmental management, natural disaster prevention and relief and transportation. In the field of waste management, locational studies such as the siting of rubbish tips, vehicle routing, and improving efficiency in suburban waste collection have been common applications of GIS.

Table 2.1: Summary of literature on people's attitude and behaviour on litter.

Citation	Aim	Data collection method	Analysis tool	Result
Tonglet, *et al.* (2004)	Understanding waste minimization behaviour	Observation, interview and survey	Correlation and regression	Recycling attitude influenced by opportunity, facilities and knowledge and Minimization behaviour is a result of concern for environment and community
Garces, *et al.* (2002)	Analyse the backgrounds of urban waste recycling behaviour	Interview	Structural Equation Models (SEM)	Environmental awareness and knowledge, positive perception of management by local government brings a positive effect on individual recycling behaviour and perceived personal difficulties (space and time), distance to and from the container have a negative effect
Ong and Sovacool (2012)	Explore littering issue from a public policy perspective	Interview and Observation	Comparison with literature	Institutions, organizations, and public norms helped in maintaining the cleanliness in Singapore while waste is valued and cleaning is considered productive and honourable in Japan
Cialdini and Reno (1990)	Understand the impact of injunctive and descriptive norms on littering	Observation and experiment	Log linear analysis	Cultural, situational and depositional factors influence one's norm
Liu and Sibley (2004)	Observation of littering along with attitudinal and structural intervention testing social space theory	Observation	Not mentioned	Attitude and behaviour relation is stronger for active litterers
Chappells, and Shove (2007)	Understand the role of dustbin as a mediator of changing waste practices	Literature research	Past literatures	Waste utilities, consumption practices and everyday waste routine play a significant role in shaping waste services
Hargreaves (2011)	Understand if pro-environmental behaviour change is within capacity of individual agents or require more fundamental structural change in society.	Observation in an organisational setting	Past Literatures	Focus should be made on group of practices co-existing together, close relationship is there between practices, power and social relations
Schulz, *et al.* (2013)	Observation of littering behaviour	Observation	Modelling, SPSS	Littering behaviour highly dependent on age, gender, attitude and motivation; every added litter bins reduce litter by 1%

This section summarises a number of studies that use GIS to optimize the use of resources via appropriate routing, reduction of bins and collection systems (Table 2.2). Karadimas and Loumos (2008) design a model to reduce the number of public litter bins by 30% and, by doing so, lower the cost of waste collection and transport. Similarly, a Triangulated Irregular Network (TIN) in GIS was used to propose a suitable type and size of bin and frequency of collection in an urban area by using population density, road networks, topology, and income group distribution (Vijay, *et al.* 2005).

There is always demand for improved performance and lower costs in any management service which operates within financial limitations. Alvarez *et al.* (2008) considers methods for designing routes and placing collection containers for paper and cardboard waste in a commercial area in Spain, including five shopping areas. Using GIS, they calculated six optimum routes for collection of waste to provide bins to 59% of shops; this improved the quality of paper and cardboard waste for recycling and hence reduced loss of those materials.

To manage waste, municipalities require large expenditure and operational measures. With the aim to improve the dynamic system of recycling pick up service, Anghinolfi *et al.* (2013) use volumetric sensors and Global Positioning System (GPS) to reduce collection and transportation cost and increase benefits from sale of recyclable materials. They find that their optimized collection process has 2.5 times higher net benefits than the pre-existing system of collection. A statistical model was used for optimization called mixed integer linear programming (MILP).

Chalkias and Lasaridi (2009) develop a methodology to optimize the waste collection system of commingled (dry recyclable) waste using government data and three scenarios in Nikea Municipality (6.65km^2 area), Greece: existing collection system, routing optimization with existing point of collection, and reallocating bin and optimizing collection. They consider other components essential for waste collection, including: driving time and time for emptying each bin. Some of the 120 and 240 litre bins were replaced by 1100 litre bins and the collection schedule was also modified. As a result, 160 bins were allocated replacing 501 original bins by modelling and using a new collection route. This helped the authority by reducing collection time, travelling distance for collection vehicles, and labour, thereby providing financial and environmental benefit to management authorities. However, this research was conducted with a top-down approach, where only government data and policies were used.

Table 2.2: Summary of literature on GIS in waste management.

Articles	Optimizing area	Model used	Facility	Result	Scale
Anghinolfi *et al.* (2013)	Improve dynamic system of recycling pick up service	MILP	Recycling pick up service	Optimized collection with 2.5 times higher than previous system	Municipality
Kao and Lin (2002)	sum of walking distance for waste picking service	SSL compared with LSC and MCL	Public recycling bins	SSL produced efficient result by shortening 10% walking distances to residents, higher quality of service	Residential area
Alvarez, *et al.* (2008)	design routes, calculate number of paper and cardboard containers	MGT algorithm	Paper and cardboard containers	Overfilling of bins not found and fewer rejection of quality of PCB	Commercial / business park
Chalkias and Lasaridi (2009)	Comparing three scenarios: existing scenario (s1) collection vehicle routing optimization (s2) and reallocation of bins and routing optimization (s3)	Network analysis ArcGIS	Dry recyclable bins	Gas emission and fuel savings achieved with s3 due to efficiency in collection time and distance travelled	Municipality
Aremu, *et al.* (2011)	Determine location of bin considering maximum coverage, environmental constrains and walking distance to service point	TransCAD and GIS	General waste bin	6-10 number of bins provided full service coverage of waste bin	Metropolitan city

Kao and Lin (2002) show that walking distance is an essential element to consider when modelling waste collection points. They compare three types of statistical models for selecting location of waste collection points in a residential area in Hsinchu City, Taiwan: LSC (Location Set Covering) to select the minimum number of locations to satisfy demands within a certain acceptable service distance; MCL (Maximum Covering Location) to obtain the combination of locations or maximum coverage; and SSL (Shortest Service Location) to minimize total walking distance by selecting nearest locations to serve each demand point. For all the models, the maximum acceptable walking distance to bin facilities was set to an arbitrary 50, 70, 85 and 100 meters. This research aimed to compare the outputs of various models and did neither consider people’s opinion on walking distances nor population density.

Modelling of waste management systems has also been carried out external to GIS via statistical models and algorithms. Hirsch (1965) assessed cost efficient waste management by using regression models to investigate the relationship between factors related to waste collection service: number of employees, stop density, characteristics of collection areas, and cost per collected weight of waste. Solomon's insertion and clustering algorithm were used by Kim, *et al.* (2006) to calculate an optimal waste collection route by minimizing driving distance and balancing workload. Buhrkal *et al.* (2012) applied a similar method to optimize a waste collection route and calculated an average saving of 13% on existing collection points by considering lunch time breaks too. McLeod and Cherrett (2008) found annual savings of travel distance of 10,000 km by applying rerouting and sharing routes of three different waste companies.

Research gaps

GIS-based optimization studies have identified locations for bin facilities and informed the decision making process. However, I could find no research that incorporated user opinion in the optimization analysis. It was also clear from the litter behaviour and attitude literature and optimization based studies that there has been very little inter-disciplinary research in litter management. Studies have either focused on optimizing current systems to reduce management cost, emissions, and time or on people's behaviour and attitude.

In a review of the multi-criteria decision analysis (MCDA) tool, Achillas, *et al.* (2013) suggest that there is a need for careful consideration of various parameters such as location of landfill, available treatment facilities, and public opinion - and that these variable are unique to different places. Including user opinion in decision making would expand the effective implementation of GIS optimization and assist planners in applying a bottom-up approach to decision making. To overcome the division between these two sectors of litter research, I intend to carry out a multidisciplinary study by bringing together social research and science to incorporate user opinion on preferred walking distances to litter bins in a GIS optimization analysis.

Most of the GIS studies were carried out in large study areas such as municipalities and urban cities. With the exception of Alvarez, *et al.* (2008), studies have not considered the enterprise scale (for example, universities, hospitals, business parks and offices). I intend to overcome this gap by performing my research at an enterprise scale by using Macquarie University as the case study area.

Chapter 3: Methods

Phase one of my research included a field visit to record and locate the number of litter bins in Macquarie University using a hand held GPS (global positioning system) (Objective 1). Population data was collected using a manual spot count and interpolated to create a population density model across the entire study area. Phase two comprised of face-to-face survey of 200 users within the study area (Objective 2). The key output of phase two was a range of distances people were willing to walk to a litter bin. The results of phase one and phase two were combined in a GIS network analysis to optimize the number and location of bins under multiple scenarios (Objective 3).

Study Site: Macquarie University

Macquarie University is located in the suburb of Macquarie Park, ~17 kilometres from Sydney Central Business District (Macquarie University, 2015; Figure 3.1). The campus covers 126 hectares and includes 13 sites of cafes and restaurants (Figure 3.1), and one train station, seven bus stops and multiple taxi stops. There are only 3 sites on campus where smoking is allowed (Macquarie University, 2013). Commercial areas and Macquarie University Hospital were excluded from my analysis because public litter bins at those locations are not managed by Macquarie University. Macquarie University has a total student population of 38,747, which includes both part time and full time students. There are 2,768 academic and professional staff located on the campus (Macquarie University, 2015).

Objective 1: Map the distribution of public litter bins and model population density

I created my own spatial data and also acquired multiple spatial layers from external agencies prior to performing my analysis (Table 3.1). All data preparation and analysis were performed using ArcGIS Software 10.2. The coordinate system of my analysis was WGS (World Geodetic System) 1984 and UTM (Universal Transverse Mercator) Zone 56S.

Digitization of buildings, roads, commercial areas, lake, creeks and roads

Roads, buildings, the lake, creeks and commercial areas were digitised in GIS using a Nearmap satellite image (Figure 3.2) as a base map. The spatial extent of the study area was digitised using a jpeg image of the campus. Commercial areas, including the Macquarie University Hospital, Cochlear, Gumnut Cottage, Siemens, etc., were erased from the study area layer as Macquarie University does not manage litter bins at those locations.

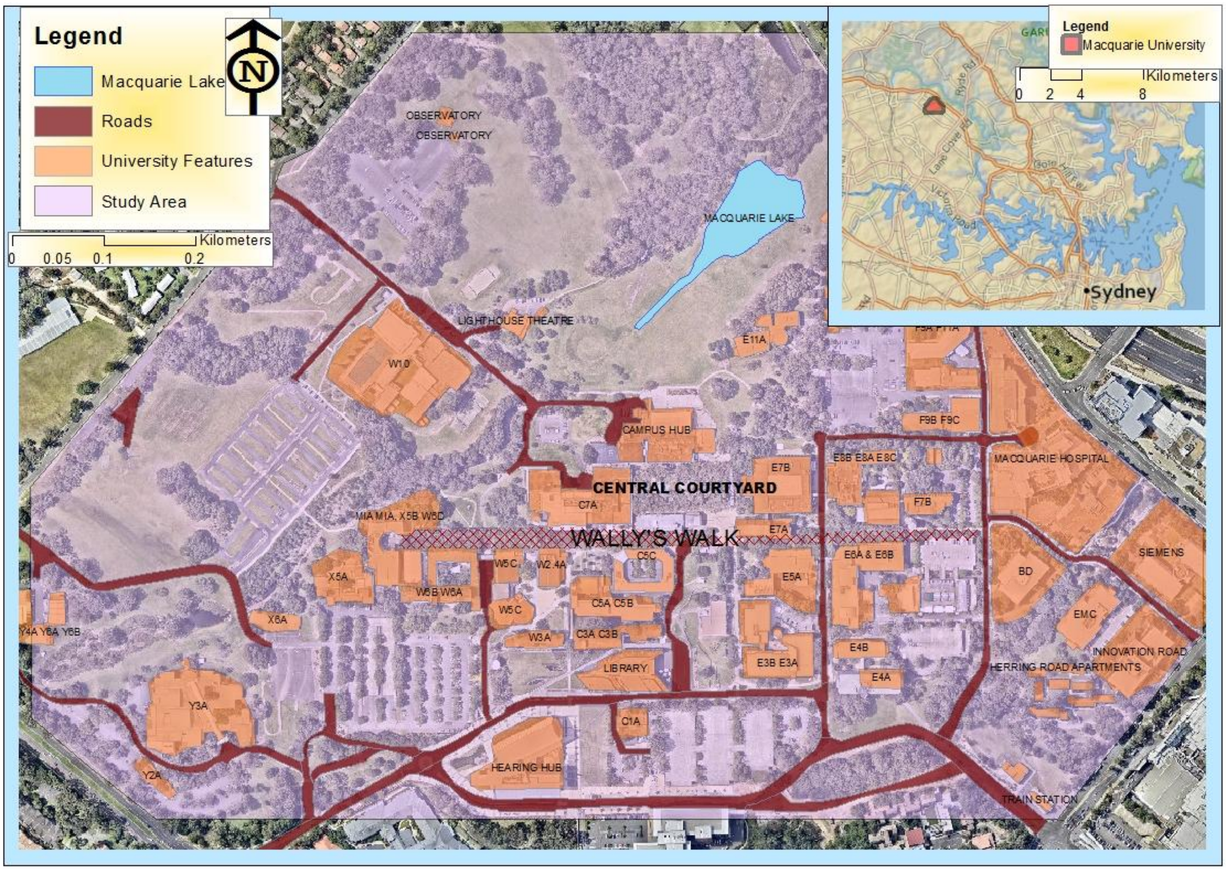

Figure 3.1: The study area of Macquarie University.

Table 3.1: Spatial data used in the analysis, their sources and geometry.

Layer	Source	Data type	Geometry
Satellite image of University	Nearmap (Figure 3.2): 21/12/14	Raster	-
Extent of study area	Macquarie University website (Macquarie University, 2013) and digitization by NN	Vector	Polygon
University features (i.e. buildings, roads, the lake, creeks and commercial areas)	Digitization from satellite image by NN	Vector	Polygon
Population count	Systematic observation by NN	Vector	Point
Location of litter bins	Collected using GPS by NN	Vector	Point
Extent of pedestrian walking routes	Digitization from satellite image by NN	Vector	Polygon

Figure 3.2: Satellite image of study area extracted from Nearmap (21/12/2014).

Litter bins

There were two sets of litter bin facilities created for data analysis. The first data set was a point shapefile of the current location of litter bins. I used a field survey (28th May to June 5th, 2015) and Garmin GPS (Global Positioning System) unit to record the current location of litter bins as waypoints (eastings and northings) within the study area. The total number of bins was validated by a second visit on 27th July, 2015. The GPS data was converted to shapefile using expertGPS (ExpertGPS, 2015). In order to align the current bin locations with the network dataset (Methods Objective 3), I used the 'near' tool in ArcGIS to snap the bin location to its nearest polyline.

The second data set is a point shapefile of the potential location of litter bins to be used in the optimization analysis. First, I erased all the features (Table 3.1) from the study area to create a layer of the spatial extent of pedestrian walking routes (area = $0.84km^2$). I then used the 'create random points' function to locate random points at a minimum spacing of 5 metres within the spatial extent of pedestrian walking routes. A small minimum distance between random points provides a high number of points and greater accuracy (Ratcliffe, 2005). However, increasing the number of random points also increases processing time and computing resources (Curtis *et al.* 2006; Marinoni, 2006). The five metre minimum distance between random points was a compromise between accuracy and computer processing power and time. In order to align the potential bin locations with the network dataset (Methods Objective 3), I used the 'near' tool in ArcGIS to snap the bin location to its nearest polyline.

Population density

Information on population distribution helps to understand the demand of litter bins in an area and hence design and locate bins at the right place to meet that demand. Some sites at Macquarie University are continually used by students and staff, including the central courtyard, library, main thoroughfares (e.g. Wally's Walk) and large lecture theatres (Figure 3.1). Other sites, including the large parkland at the north of the campus, are rarely used by staff and students. Variation in the population's use of space occurs across the day (e.g. early morning, lunchtime, late afternoon). I conducted a pre-screening field trip during the Semester 1 teaching period (8th - 12th June) to understand the population movement behaviour before the actual population survey. This helped me to identify variation in population density across the study area and at different times of the day. From the pre-screening, it was found that entry points to Macquarie University (car parks, the train station and bus stops) had peak pedestrian movement during the morning 8 - 10 am and afternoon 3 - 5pm. The central area of Macquarie University, including Wally's Walk, the library and central courtyard (Figure 3.1), had a peak volume during the day from 12-2 pm when students and staff are moving between lectures or eating their lunch.

To ascertain pedestrian volume within the University, I identified 70 locations of varying population density across the study area for manual spot counts. Spot counts were made from a fixed position away from a screen line (imaginary line) (Schneider, *et al.* 2008). The number of pedestrians crossing the screen line (in narrow walkways) or 10 X 10 metre transect areas were recorded within a five minute time frame. *I included* people walking in both directions in the count. The time of day spot counts were made depended on the use of the site ascertained in the pre-screening assessment i.e. spot counts near car parks, train station and bus stops occurred during the peak times of morning and afternoon, and in the central areas during lunch time.

I converted the data from the manual pedestrian count to a unit of population/m^2 and uploaded to GIS as a point shapefile. The population data was interpolated to the spatial extent of the entire study area using the Inverse Distance Weighted (IDW) method. IDW is an operation of moving window where values are assigned to empty raster grid according to the values of those centre grids. This method assumes that population density decreases as you move away from the sample grid (Mennis, 2008). It determines a cell value using a linear weighted combination set of sample points (Childs, 2004). A raster grid of population density was generated using the 'IDW' tool in ArcGIS at a resolution of 5 meters. In order to use the population data in a network analysis in ArcGIS, the raster layer was converted to vector point shapefile (n = 20,940) representing individual demand points.

Objective 2: Ascertain the willingness and attitude of staff and students to walk to litter bins.

To understand the willingness and attitude of users to public litter bins, it is essential to get their opinion. There are multiple methods to extract opinion from survey participants, such as interview or online/post survey. Due to the ease of access to survey participants, I chose to conduct face-to-face surveys. I developed a questionnaire to use during the face-to-face surveys to ascertain people's willingness to walk to a litter bin along with their attitude towards litter. The questionnaire was loaded onto an iPad using the Qualtrics online survey software to facilitate the collection of data in the field. Qualtrics enabled me to quickly record survey responses in the field and it also automatically collated the data in an electronic spreadsheet. The survey had three sections (Figure 3.3):

Background information: Questions on gender, age and designation were asked for the purpose of obtaining responses from a wide range of participants (Questions 2, 3, and 4).

Maximum willingness to walk: Instead of directly asking survey participants 'what is the maximum distance you are willing to walk to a bin before littering', which could result in false answers as people generally don't want to admit to littering, an indirect question was formulated. The location of the survey was noted at the beginning of the survey (Question 1). Survey participants were asked to show their destination in the study area on a map (Question 5). A follow-up question was asked on how many bins they think is required between their current location and their destination (Question 6).

Attitude and behaviour: In order to understand user's attitude towards litter, participants were asked their opinion on littering in the study area, reasons for littering and solutions to reduce the litter problem (Questions 7, 8, 9, and 10).

1. Survey location ....

2. Gender

   a. Male
   b. Female
   c. Other

3. Age

   a. 18-25
   b. 26-35
   c. 36-45
   d. 46-55
   e. 56-65
   f. 66-75
   g. 75+

4. Are you a................................

   a. Staff member
   b. Student
   c. Other

5. Where are you going now/next (show in the map)? ....

6. How many 240L bins do you think is required from here to your destination mentioned above? (bins emptied every day) ....

7. Is litter a problem in Macquarie University?

   a. Yes
   b. No
   c. Don't Know

8. Where is the problem? ....

9. Why do you think people litter there?

   a. Cannot find a bin
   b. Overflowing bin
   c. When it is unhealthy/unclean to hold litter
   d. Hurry
   e. Accident
   f. Awareness
   g. Too many to carry
   h. Don't Know
   i. Any other

10. Do you think changing following would help reduce litter? Could you explain your answer please?

   a. Increasing number of bins: ....
   b. Relocating bins: ....
   c. No: ....

Figure 3.3: Questions formulated for the face-to-face interviews of user preferences and attitudes towards public litter bins.

Due to limited time and resources, a purposive sampling approach was chosen to select survey participants. Purposive sampling is a type of non-scientific sampling based on theory each sample unit represents the total population and are selected according to the purpose of the researcher (Paler-Calmorin and Calmorin, 2007). I assumed that all the respondents have used litter bins at Macquarie University and therefore have preferences or knowledge about bin use. Survey participants either worked or studied at or were visiting Macquarie University and therefore share a common background of using space in the study area. This sampling type is specifically known as homogenous sampling.

The survey methodology and questionnaire were approved by Macquarie University's ethics committee in July 2015 (Reference number: 5201500370). The face-to-face surveys were conducted over two weeks during the Semester 2 teaching period from 28th July - 7th August, 2015. During the pre-screening of population distribution, I found the most number of people present at or near the train station, central courtyard, library and Wally's Walk. These areas were chosen for approaching potential survey participants for the face-to-face interview. People were approached with a request to take part in the survey. Only those above 18 years of age and who agreed to be a part of the survey were used as survey participants. The process of approaching survey participants was continued until the response number reached 200.

Analysis of questionnaire data

After 200 surveys were completed, I used the following methods to analyse the survey responses:

- I used Google Maps to measure the walking distance between each participants' survey location and their destination (Questions 1 and 5).
- The distance between each participant's current location and destination was divided by their response to Question 6 to find the preferred distance he/she is willing to walk to a litter bin.
- The preferred distance participants were willing to walk was sorted from low to high, and the following values calculated in order to obtain information on distances the survey group were willing to walk to bins: maximum distance of the lowest 10, 30, 50 and 70% of reported distances, and highest reported distance.

Objective 3: Undertake an optimization analysis combining the outputs of Objectives (1) and (2) to develop a range of bin locations in the study area

I prepared a network data set of pedestrian routes to be used in the optimization analysis. Unlike cars on roads, pedestrians may take any course to walk on so there are no set routes. I used the spatial extent of pedestrian walking routes layer (Table 3.1) to create the network dataset. The network of pedestrian routes was created at two resolutions. The southern half of Macquarie University of highest population density was converted to a raster grid of 1 meter resolution. The raster grid was then converted into polylines to create a vector layer of pedestrian's routes. The northern half of the campus was converted to a polyline using the same process, but with a resolution of 10 meters. Two resolutions were chosen as a compromise between accuracy and computer processing power and time. The two polyline layers of varying resolutions were merged together to create a network dataset (Figure 3.4). The network dataset contained 626,412 arcs (individual polylines) and 316,006 nodes (node are points of intersection where two arc meets). The network did not include z-coordinates (i.e. elevation).

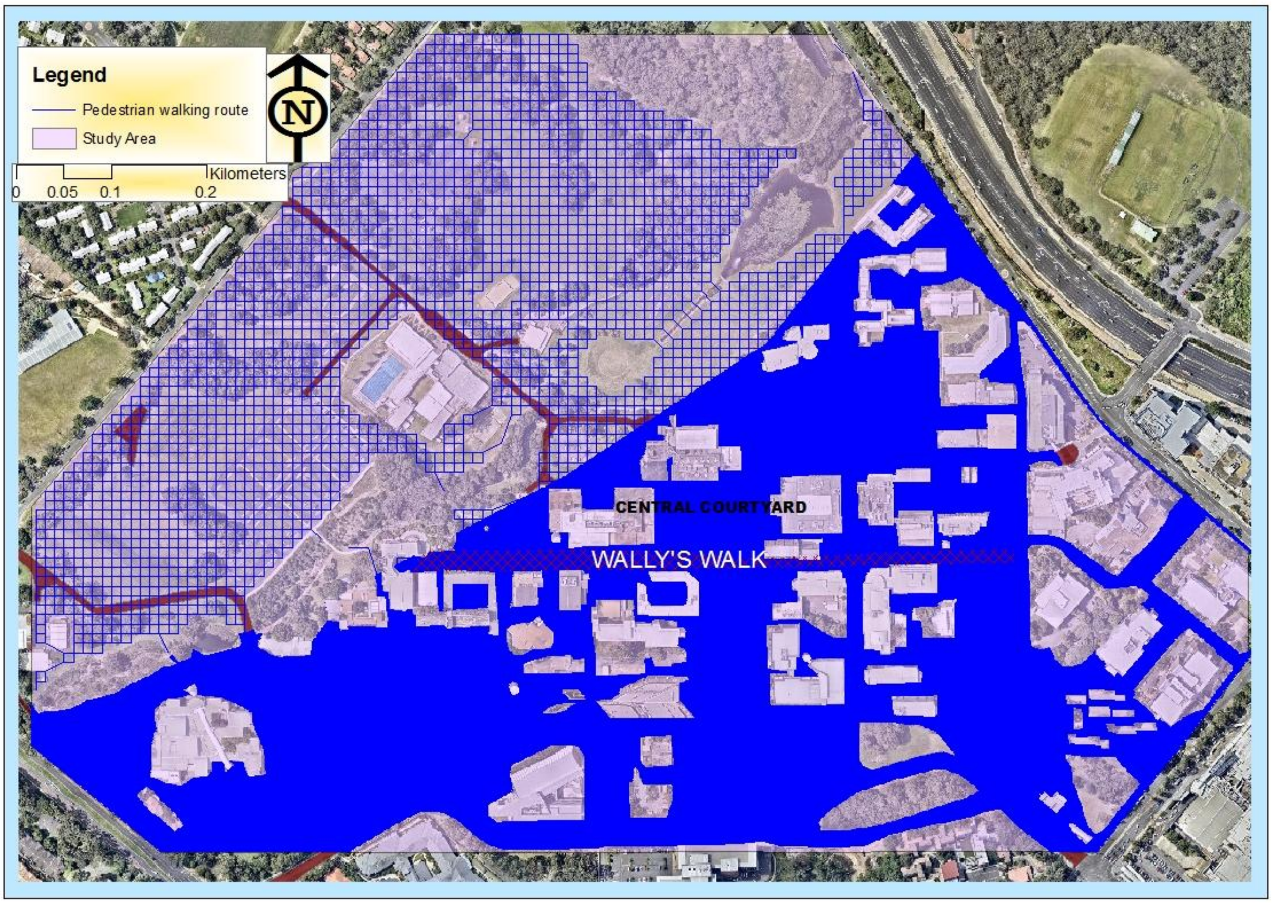

Figure 3.4: Preparation of network dataset within study area using polylines for network analysis.

Optimization of litter bins was performed using the Network Analyst extension in ArcGIS. The extension enables the modelling of realistic network conditions to locate the: shortest route, most efficient route, and closet facilities; and also to determine optimal locations for facilities using location allocation analysis (ESRI, 2011). The location allocation model has been used to optimize the location of facilities such as fire stations, housing projects, and police stations in urban areas (Valeo, *et al.* 1998, Algharib 2011). A study by Valeo, *et al.* (1998) was one of the first to incorporate this method. They used the model to locate recycling depots in a city, considering both walking and driving distance. The method was considered effective in finding appropriate locations for recycling depots in an urban environment by maximizing the coverage of depot sites in the town of Dundas, Ontario.

In this analysis, the location allocation tools (a subset of tools in the Network Analyst extension) were used to solve the problem of siting litter bin facilities under multiple scenarios. With a given number of candidate facilities and any amount of demand points (with or without a weight), location allocation helps to choose a subset of candidate facilities such that the sum of weighted distances from each demand point to the closest facility is minimized below a specified distance (or impedance value) (ESRI, 2015). In this study, facilities were litter bins, impedance values were the distances people preferred to walk to bins, and demand points were the points of population density.

Five location-allocation problem types were used to optimize locations of litter bins at Macquarie University under multiple scenarios. I used five problem types as it is essential to compare multiple approaches when population demand and location of bins is not equally distributed (Abramovich 2012). Using five problem types also enabled me to use develop scenarios to answer questions such as: where should new bins be added to the current distribution of bins to meet demand and user preferences; and what current bins could be removed with effecting demand and user preferences? The maximize attendance problem type optimizes bin locations using population data while maximize coverage does not use population data. The minimize facilities problem type minimizes the number of bins to meet population demand, while minimize impedance does not use data on preferred walking distances. The target market share problem type adds new bins to the current location of bins to meet population demand. The location-allocation problem types are defined in detail below:

I. Maximize attendance

The location of a fixed number of litter bins is optimized such that as much population demand as possible is allocated to each litter bin within a specified distance (i.e. distance people preferred to walk to bins). This problem type and scenario assumed that the further people have to walk to reach a litter bin, the less likely they are going to use it.

II. Maximize coverage

The location of a fixed number of litter bins is optimized such that as many demand points as possible are allocated to bins within a specified distance. This problem type and scenario does not take into account the population demand and only considers the distance to demand points.

III. Minimize facilities

The number of bins required to cover the population's demand is minimized within a specified distance. Like the maximize coverage problem type, litter bins are located in such a way that as many demand points are allocated to each bin within a specified distance. However, it is not constrained by a fixed number of bins.

IV. Minimize impedance

In this problem type, a fixed number of bins are allocated in space considering only population demand (i.e. distance people preferred to walk to bins is not included in the analysis). This problem type and scenario assumed that people will use the nearest litter bin available, regardless of how far they need to walk.

V. Target market share

The target market share problem type adds a minimum number of litter bins necessary to the current distribution of bins to meet a specified percentage of the population density. This problem type and scenario chooses the fewest number of litter bins necessary to capture the population demand.

Scenarios

Using the location allocation problem types described above and multiple distances people preferred to walk to bins (Objective 2), I designed 56 scenarios for litter bin distributions within Macquarie University. The scenarios fitted into four themes:

1. Adding more bins to meet demand and user preferences whilst retaining the current location of bins

In this scenario, the maximize attendance problem type was used to allocate an additional 10 and 20% of bins on top of the current bin distribution and number (n = 194) to meet both population demand and the distance preferences of users (Table 3.2). This scenario would be used by managers if they wanted to add more bins to the current location of bins to meet both demand and user preferences. To assess the difference in bin distributions when population demand was not included, a maximize coverage problem type was also used (Table 3.2).

Table 3.2: Scenarios for adding more bins to meet demand and user preferences whilst retaining the current location of bins.

Problem Type	No. of facilities	Impedance cut-off	Impedance transformation	Population demand included?	Appendix Figure No.
1.1.Maximize attendance (adding 10% bins)	214	38	Linear	Yes	1.1
	214	52	Linear	Yes	1.2
	214	63	Linear	Yes	1.3
	214	80	Linear	Yes	1.4
	214	400	Linear	Yes	1.5
1.2.Maximize attendance (adding 20% bins)	233	38	Linear	Yes	2.1
	233	52	Linear	Yes	2.2
	233	63	Linear	Yes	2.3
	233	80	Linear	Yes	2.4

	233	400	Linear	Yes	2.5
1.3.Maximize coverage (adding 10% bins)	214	38	Linear	No	3.1
	214	52	Linear	No	3.2
	214	63	Linear	No	3.3
	214	80	Linear	No	3.4
	214	400	Linear	No	3.5
1.4.Maximize coverage (adding 20% bins)	233	38	Linear	No	4.1
	233	52	Linear	No	4.2
	233	63	Linear	No	4.3
	233	80	Linear	No	4.4
	233	400	Linear	No	4.5

2. Redistributing the current number of bins to meet demand and user preferences

In this scenario, the maximize attendance problem type was used to redistribute the current number of bins (n = 194) to meet both demand and user preferences (Table 3.3). This scenario would be used by managers if they wanted to keep the same number of bins but redistribute them so that they meet both demand and user preferences. To assess the difference in bin distributions when population demand was not included, a maximize coverage problem type was also used (Table 3.3). To assess the difference in bin distributions when both population demand and user preferences were not included, a minimize impedance problem type was also used (Table 3.3).

Table 3.3: Scenarios for redistributing the current number of bins to meet demand and user preferences.

Problem type	No. of facilities	Impedance cut-off	Impedance transformatio n	Population demand included?	Appendix Figure No.
2.1. Maximize attendance	194	38	Linear	Yes	5.1
	194	52	Linear	Yes	5.2
	194	63	Linear	Yes	5.3
	194	80	Linear	Yes	5.4
	194	400	Linear	Yes	5.5
2.2. Maximize coverage	194	38	Linear	No	6.1
	194	52	Linear	No	6.2
	194	63	Linear	No	6.3
	194	80	Linear	No	6.4
	194	400	Linear	No	6.5
2.3. Minimize impedance	194	n/a	Linear	No	7

3. Minimize the number and location of bins to meet demand and user preferences

In this scenario, the minimize facilities problem type was used to create a new distribution of litter bins that minimizes the number of litter bins that meet user preferences but not population demand (Table 3.4). The target market share problem type was used in conjunction with the current location of bins to allocate new bins to sites that capture 10 or 20% of the population demand (Table 3.4). These scenario would be used by managers if they wanted to minimize costs by either allocating bins based on user preference alone, or to ensure that any new bins were allocated to sites of greatest demand.

Table 3.4: Scenarios for minimizing the number and location of bins to meet demand and user preferences.

Problem Type	Percent of market share	Impedance cut-off	Impedance transformation	Population demand included?	Number of bins allocated	Appendix Figure No.
3.1. Minimize facilities	n/a	38	Linear	No	398	8.1
	n/a	52	Linear	No	227	8.2
	n/a	63	Linear	No	161	8.3
	n/a	80	Linear	No	109	8.4
	n/a	400	Linear	No	11	8.5
3.2 Target market share	10	38	Linear	Yes	12	9.1
	10	52	Linear	Yes	10	9.2
	10	63	Linear	Yes	9	9.3
	10	80	Linear	Yes	7	9.4
	10	400	Linear	Yes	7	9.5
3.3 Target market share	20	38	Linear	Yes	31	10.1
	20	52	Linear	Yes	23	10.2
	20	63	Linear	Yes	20	10.3
	20	80	Linear	Yes	17	10.4
	20	400	Linear	Yes	23	10.5

4. Reducing the number of litter bins

In this scenario, the maximize attendance problem type was used to allocated 10 and 20% fewer bins to meet both demand and user preferences (Table 3.5). This scenario would be used by managers if they wanted to reduce the current number of bins so that they meet both demand and user preferences.

Table 3.5: Scenarios for reducing the number of litter bins from current distribution.

Problem Type	No. of facilities	Impedance cut-off	Impedance transformation	Population demand included?	Appendix Figure No.
4.1. Maximize attendance (reducing 10% bins)	174	38	Linear	Yes	11.1
	174	52	Linear	Yes	11.2
	174	63	Linear	Yes	11.3
	174	80	Linear	Yes	11.4
	174	400	Linear	Yes	11.5
4.2. Maximize attendance (reducing 20% bins)	155	38	Linear	Yes	12.1
	155	52	Linear	Yes	12.2
	155	63	Linear	Yes	12.3
	155	80	Linear	Yes	12.4
	155	400	Linear	Yes	12.5

Chapter 4: Results

This chapter presents the results of my thesis based. Similar to Chapter 3, results are grouped according to the objectives my study.

Objective 1: Map the distribution of public litter bins and model population density

Litter bins

I found a total of 191 litter bins in Macquarie University during my first field trip, and an additional 3 bins on my second field trip (n = 194; Figure 4.1). Most of the litter bins were concentrated in the central section of Macquarie University, particularly in and around the central courtyard and Wally's Walk. The location of potential litter bins (n = 3,822) used in the network analysis is shown in Figure 4.2.

Population density

The 70 locations and population counts used for modelling population density are provided in Figure 4.3. The sites of highest population count were the: central courtyard (n = 56), library entrance (n = 41) and the walking route from Macquarie train station to building E4A (n = 61). Sites of smallest population count were in the northern area and near Macquarie Lake and building W10.

The 70 locations and population counts were used in an IDW interpolation to model population density to the spatial extent of the study area (Figure 4.4). The central courtyard, train station, and areas surrounding buildings E4B, E4B had the highest population density (37 - 60 people/m^2). The areas of lowest population density (< 5 – 18 people/m^2) occurred towards the northern boundary of the campus.

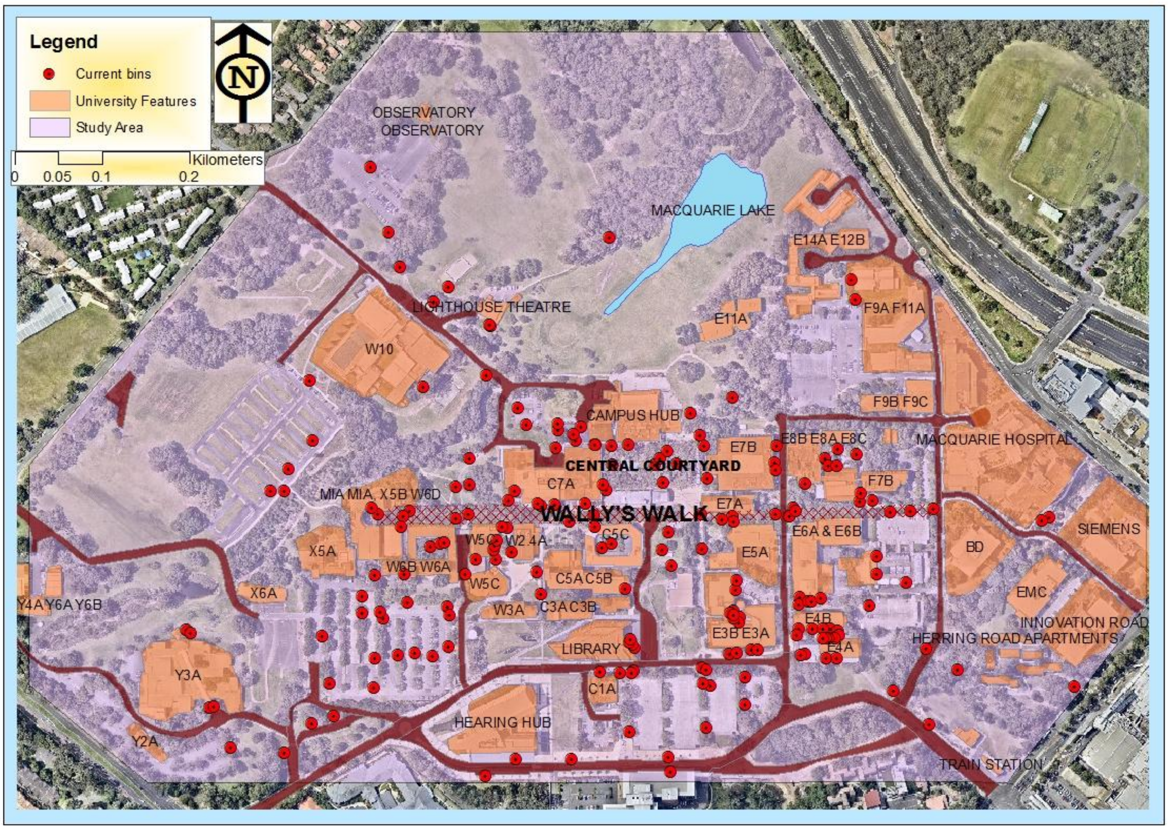

Figure 4.1: Spatial distribution of current litter bins in Macquarie University.

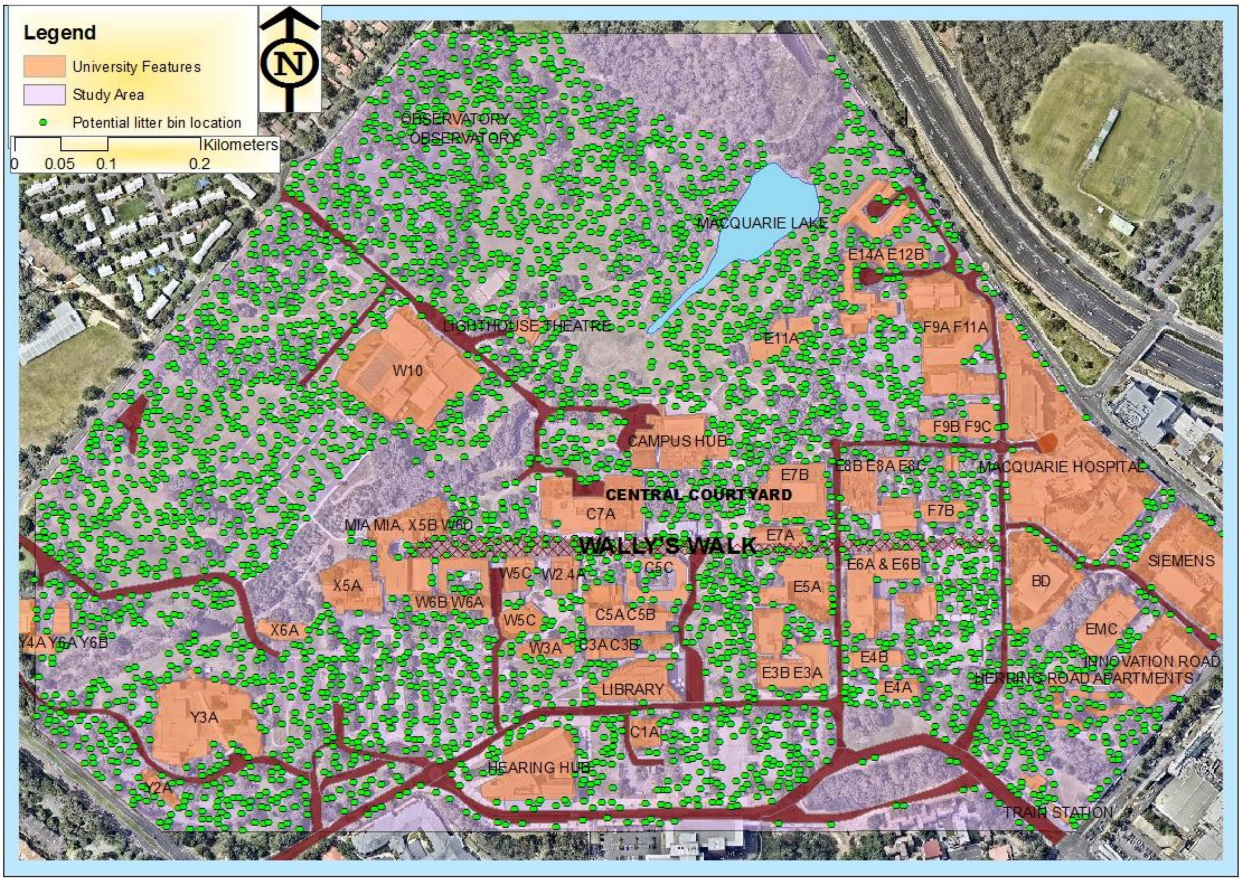

Figure 4.2: Potential location of litter bins, mapped to the spatial extent of walking routes.

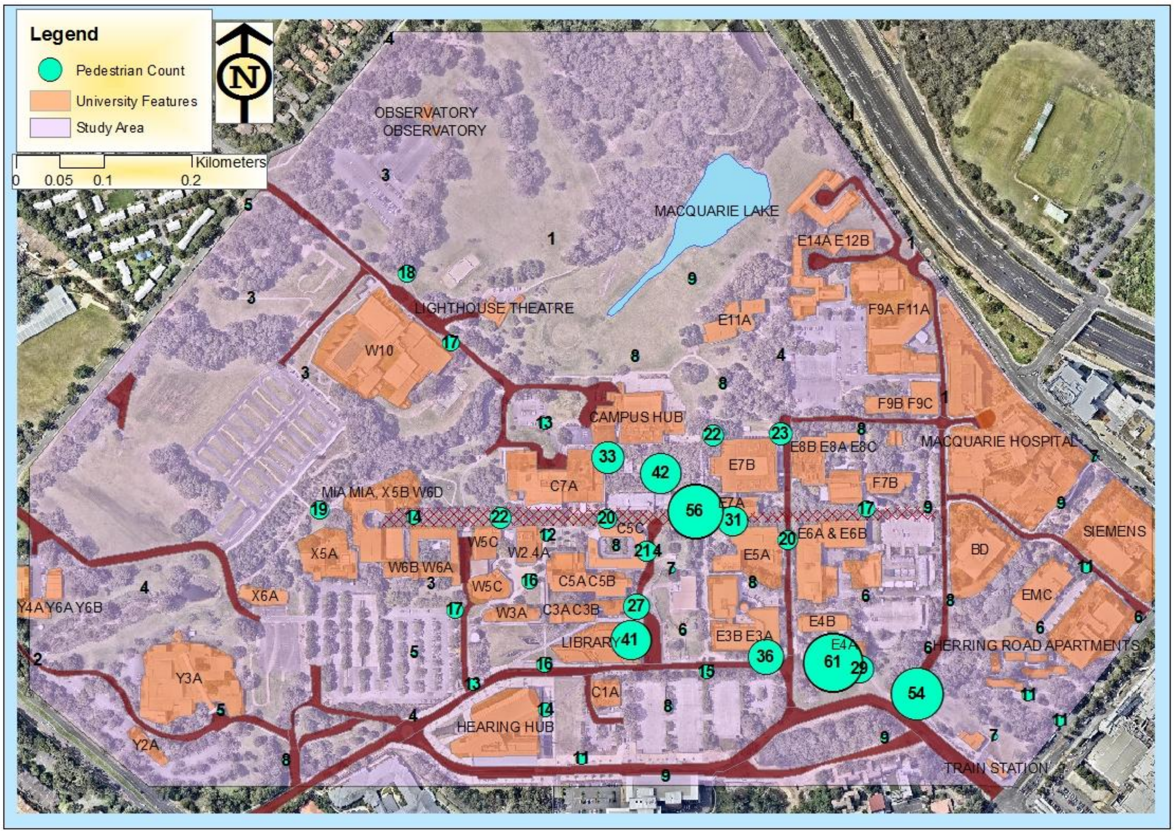

Figure 4.3: Results of population counts at 70 locations within Macquarie University.

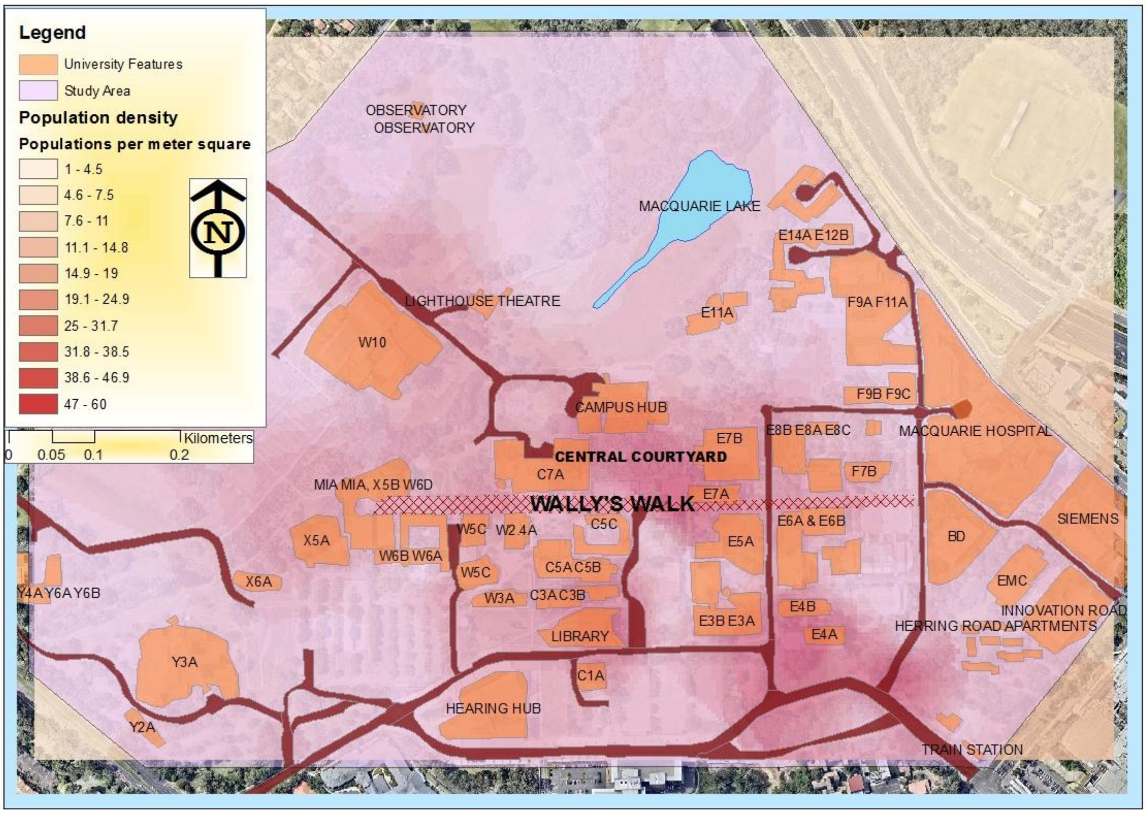

Figure 4.4: Population density model using population counts and the IDW interpolation method (Natural Jenks classification).

Objective 2: Ascertain the willingness and attitude of staff and students to walk to litter bins

I surveyed 200 people to understand user preferences on the distance people were willing to walk to bins and attitude towards litter. However, 6 surveys were not uploaded to the online Qualtrics system and were not included in the analysis. Out of the 194 survey responses, 60% were female and 40% were male. Most of the survey participants were below 35 (18-25 = 46%; 26-35 = 39%) because the highest number of survey participants were Macquarie University undergraduate and postgraduate students (n = 160). The survey participants also included 32 staff members and 2 visitors to the study area. There were a large number of student participants relative to staff because Macquarie University currently has 38,747 students and only 2,768 staff (Macquarie University, 2015).

Most (73%) of the survey participants thought that Macquarie University did not have a litter problem, and 26% believed that it did have a litter problem. Participants thought that litter primarily occurred in seating areas (n = 16), including the central courtyard and around building E4B, smoking areas, carparks, bus stops and at the entrances to the campus. When asked about their opinion on why people litter, a large proportion of survey participants (31%) thought the reason was laziness. Other reasons included not finding a bin, people in a hurry and overflowing bins (Figure 4.5).

In response to Question 10 on whether increasing the number of bins or relocating bins would help reduce litter, 131 survey participants were in favour of increasing the number of bins, 8 survey participants were in favour of relocating bins, and 107 survey participants thought that only increasing the number or changing the location of bins would not help littering (Table 4.1). When asked why they thought increasing the number or changing the location of bins were not the only solutions, survey participants replied that people need to be educated about the impact of litter to the environment through regular campaigns (n = 62). Participants also suggested other solutions, such as increased regulation and stricter penalties for litterers. Survey participants also suggested it was important to use rewards for non-litterers, maintaining cleanliness of environment by management, keeping bins clean and putting lids on them, and for users to exhibit personal responsibility.

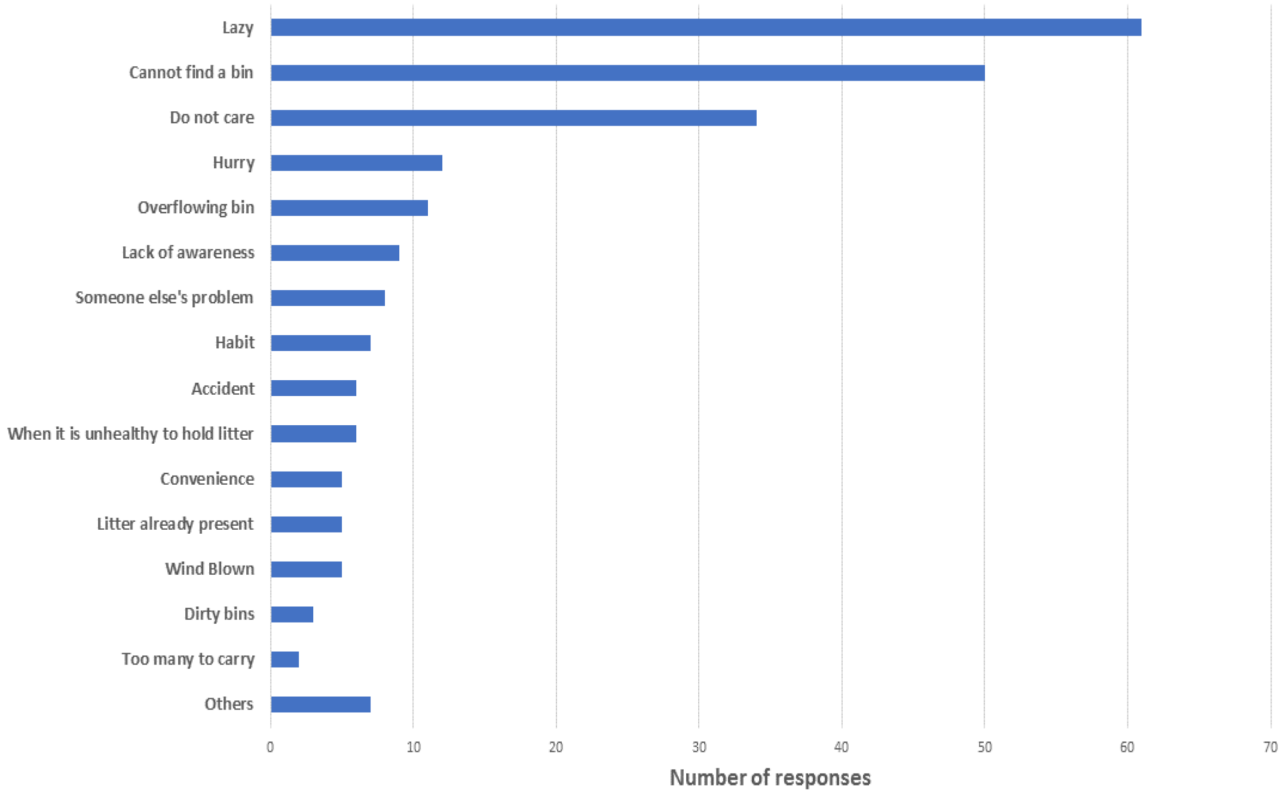

Figure 4.5: Survey response to Question 9: Why do you think people litter?

Table 4.1: Survey response to Question 10: Would changing the location or number of bins reduce littering?

Response	Number of responses
Increasing number of bins	131
Relocating bins	8
Are there other options?	107

Table 4.2: The preferred distances to walk to litter bins used in the network analysis.

Survey responses	Distance (meters)
Response of 10% participants	38
Response of 30% participants	52
Response of 50% participants	63
Response of 70% participants	80
Maximum distance	400

The distance that individual survey participants preferred to walk to a litter bin (Figure 4.6) were extracted from Questions 1, 5 and 6 (Figure 3.3). The average distance across individuals was 80 meters, the minimum distance 9.4 meters and the maximum distance 400 meters (Figure 4.6). I collated multiple distances to be used in the network analysis (Objective 3) by sorting the individual distances from lowest to highest, and then finding the maximum distance of the lowest 10, 30, 50 and 70% of survey responses (Table 4.2). For example, 38 metres was the maximum distance of the 10% of survey participants who reported the lowest distances.

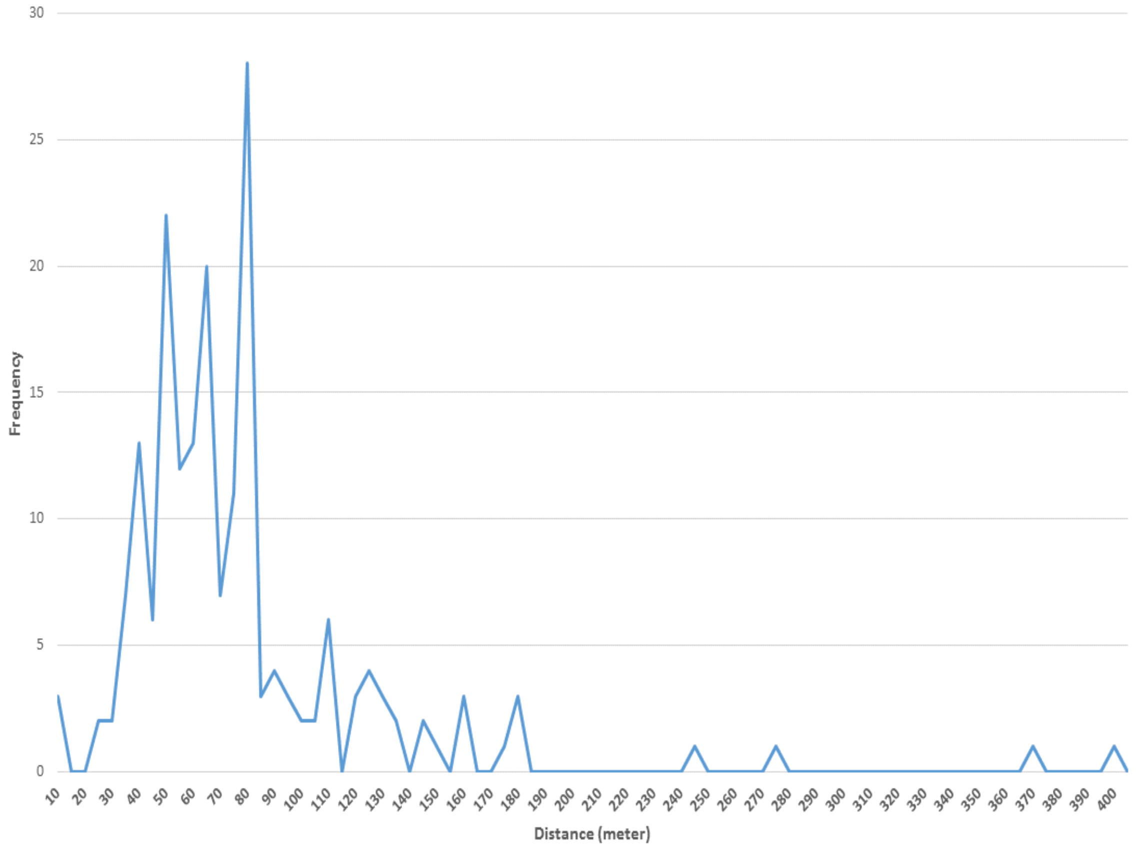

Figure 4.6: Frequency histogram of the preferred distance (metres) to walk to litter bins by survey participants.

Objective 3: Undertake an optimization analysis combining the outputs of objectives (1) and (2) to develop a range of bin locations in the study area.

Scenario 1: Adding more bins to meet demand and user preferences whilst retaining the current location of bins

Adding 10% of litter bins to the current bin distribution resulted in allocating an additional 20 bins to the study area (Table 3.2). With the application of the maximize attendance problem type, bins were positioned towards higher population density areas (Appendix Figures 1.1 – 1.5). At the minimum impedance (i.e. the distance people preferred to walk to litter bins) of 38 meters, bins were allocated to high density areas only. As impedance increased, the distances between bins increased and new bins were allocated to low density areas. Applying the maximize attendance problem type but allocating an additional 20% (n = 39) litter bins (Table 3.2) to the current bin distribution revealed a similar pattern i.e. impedance was directly proportional to distance between bins (Appendix Figures 2.1 – 2.5).

Applying the maximize coverage problem type to allocate an additional 10 and 20% of bins to the current bin distribution (Table 3.2) presented different solutions to the maximize attendance problem type because population demand was not included. Bins were allocated away from current bins at an approximate equidistant depending on the impedance because the solution was not affected by variations in population density (Appendix Figures 3.1 - 3.5 and 4.1 - 4.5).

Scenario 2. Redistributing the current number of bins to meet demand and user preferences

In this scenario, 194 bins were positioned at new locations across the study region (Table 3.3). Using the maximize attendance problem type, bins were located closer together in high population density areas and further apart in low density areas (Appendix Figures 5.1 - 5.5). When population density was not included in the analysis (i.e. maximize coverage problem type), bins were allocated across the study area at an approximate equidistant depending on the impedance (Appendix Figures 6.1 to 6.5). Similarly, when the minimize impedance problem type was applied, bins were allocated across the study area to minimize the overall distance between bins (Appendix 7).

Scenario 3. Minimize the number and location of bins to meet demand and user preferences

There were two problem types used to find solutions that minimize the number of facilities to meet demand and user preferences: minimize facilities and target market share (Table 3.4). For the problem type of minimize facilities, the minimum number of bins calculated to satisfy the impedance cut-offs (i.e. distance users preferred to walk to litter bins) was 11 bins for 400m impedance and 398 bins for 38m (Table 3.4; Figure 4.7). Since population density does not affect the minimize facilities problem type, distances between the location of bins were more or less equal (Appendix 8.1 to 8.5). When the target market share problem type was applied, the minimum number of bins was added to the current distribution of bins to satisfy a 10% and 20% market share of the population demand. At 10% market share, the total number of bins added to the current distribution of bins was 12 for 400m impedance and 7 for 38m (Table 3.4; Figure 4.7; Appendix Figures 9.1 – 9.5). 2-3 times the number of litter bins were allocated when the percentage of market share was increased to 20% (Table 3.4; Appendix Figures 10.1 – 10.5).

Scenario 4. Reducing the number of litter bins

The maximize attendance problem type was used to identify 20 (10%) and 39 (20%) litter bins that could be removed but would still meet demand and user preferences (Figure 4.8). When compared to the current distribution of bins, the solution was to reduce the number of bins from areas where they were closely positioned together, such as: near the library, eastern buildings such as E3A, behind E8A and E8C, in between E4B and E4A, and W5C and W6B (Appendix Figures 11.1 – 11.5 and 12.1 – 12.5). Even though litter bins are currently closely placed in the central courtyard, the solutions did not remove any bins from this region due to its high population density.

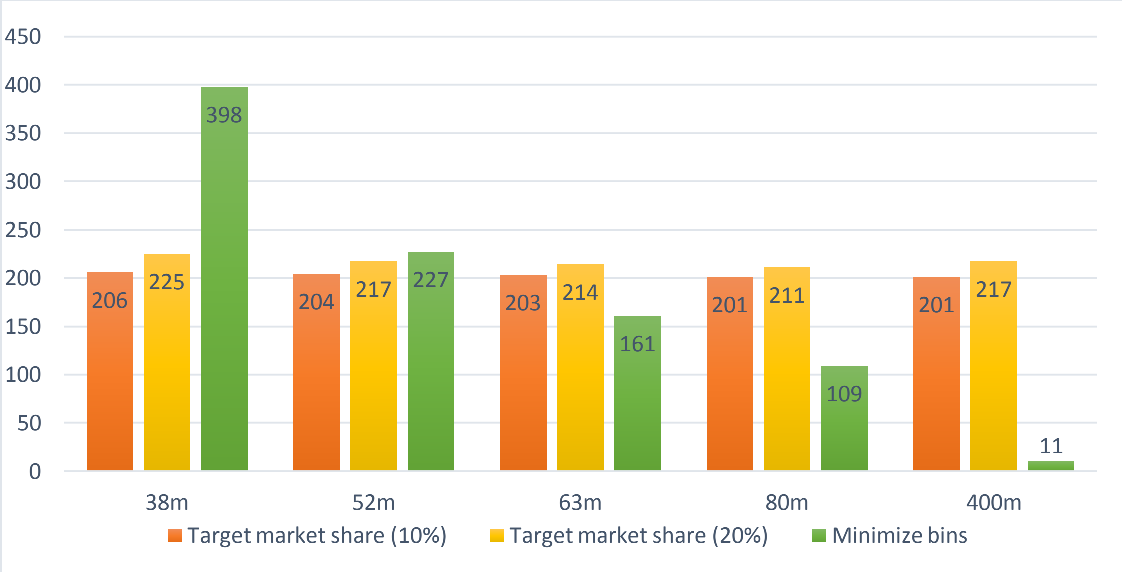

Figure 4.7: Optimized number of bins using target market share and minimize facilities problem type at multiple impedance distances.

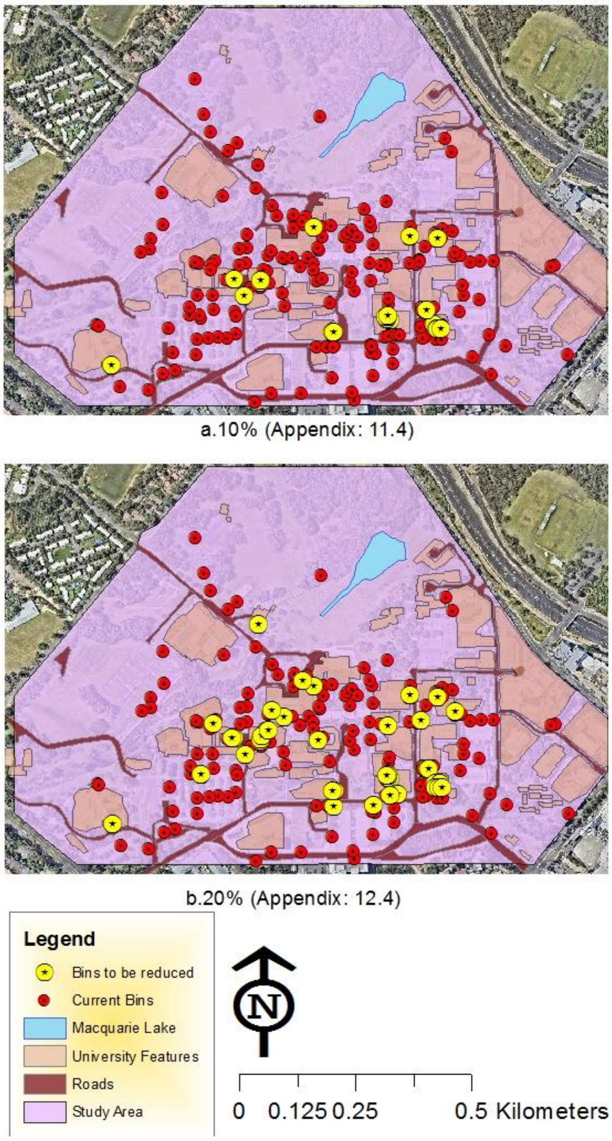

Figure 4.8: Reducing the current number of litter bins using maximize attendance problem type by 10% and 20% at 80 meters impedance cut-off.

Effect of demand and users preferences on the spatial distribution of bins

Varying the distances people were prepared to walk to bins (Table 4.2) resulted in the different positioning of litter bins under each of the four scenarios and various problem types. For example, Figure 4.9 shows the distribution of 194 litter bins at the five impendence values using the maximize attendance problem type under Scenario 2: *Redistributing the current number of bins to meet demand and user preferences.* The 194 bin locations were distributed to achieve the maximum utilization of bins whilst also keeping within the impedance distance. However, the distribution of bins did not change much after distance 63m because of the size of the ratio of size of the study area and number of bins.

The location of litter bins for several of the scenarios and problem types were also affected by population density or demand (Figure 4.4). The solutions allocated a higher density of bins to regions of high demand areas (e.g. central and south eastern areas), and a lower density of bins to regions of low demand (Figure 4.10), regardless of the number of bins used in the scenario. For example, under Scenario 1: *Adding more bins to meet demand and user preferences whilst retaining the current location of bins*, bins were allocated to high demand areas (Figure 4.10a, c, and e). However, the density of bins was still affected by the impedance value. In problem types where population demand was not included, bins were allocated nearly equidistant (Figure 4.10b, d and f).

Effect of problem type on the spatial distribution of bins

Figure 4.11 provides solutions to different scenarios and problem types that use the same impedance value (52 metres). The maximize attendance problem type allocated 20 new bins away from current litter bins and in high demand areas (Figure 4.11a). 20 new bins were placed nearly equidistant apart in the case of the maximize coverage problem type, which does not include population demand (Figure 4.11b). Similarly, the problem type of minimize facilities also does not include population density, therefore 227 bins were placed nearly equidistant apart (Figure 4.11c). The target market share problem type added 7 new bins to areas of highest population demand (Figure 4.11d).

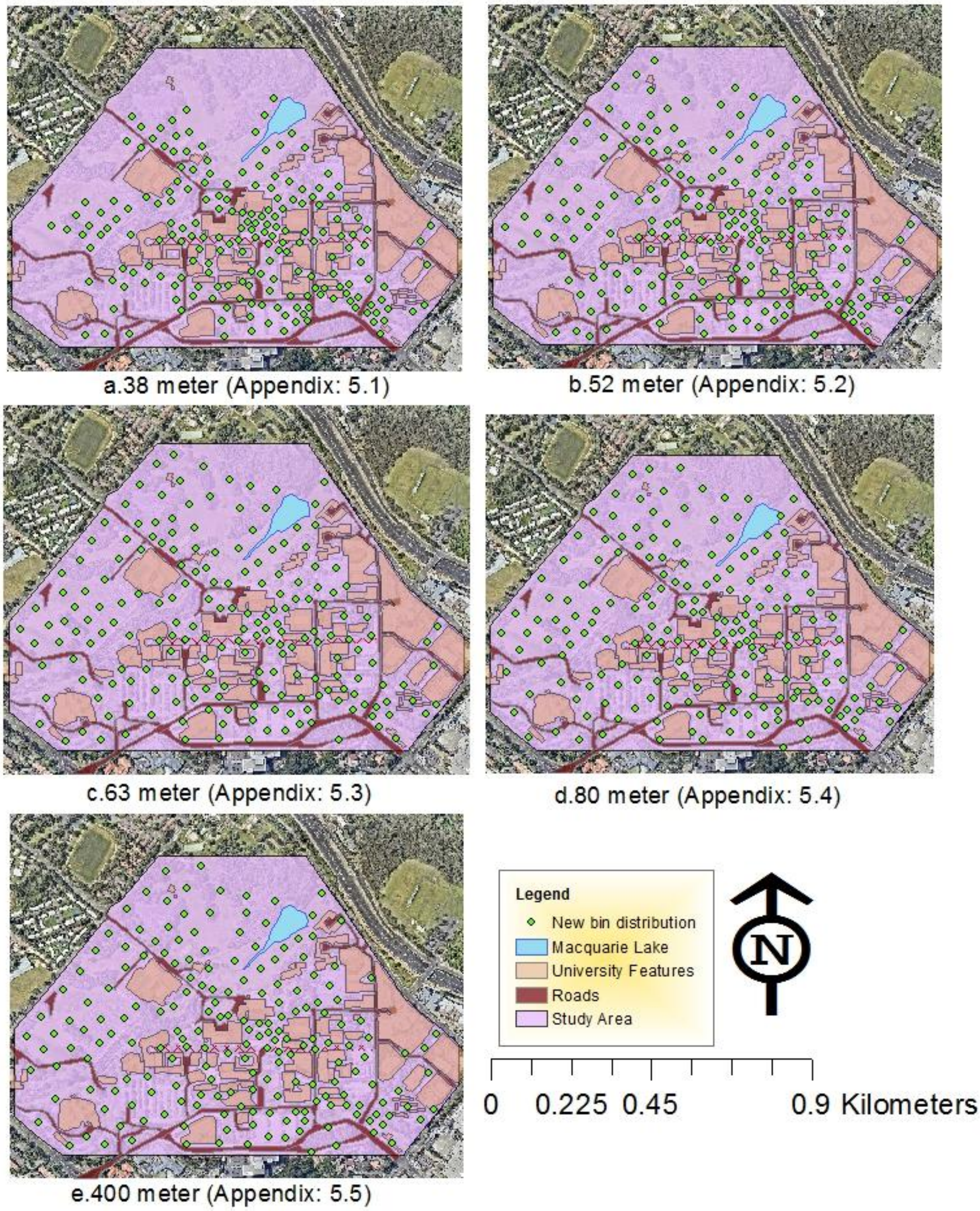

Figure 4.9: Optimizing the location of bins considering demand and user preferences using maximize attendance problem type and number of bins 194 with various impedance cut-offs.

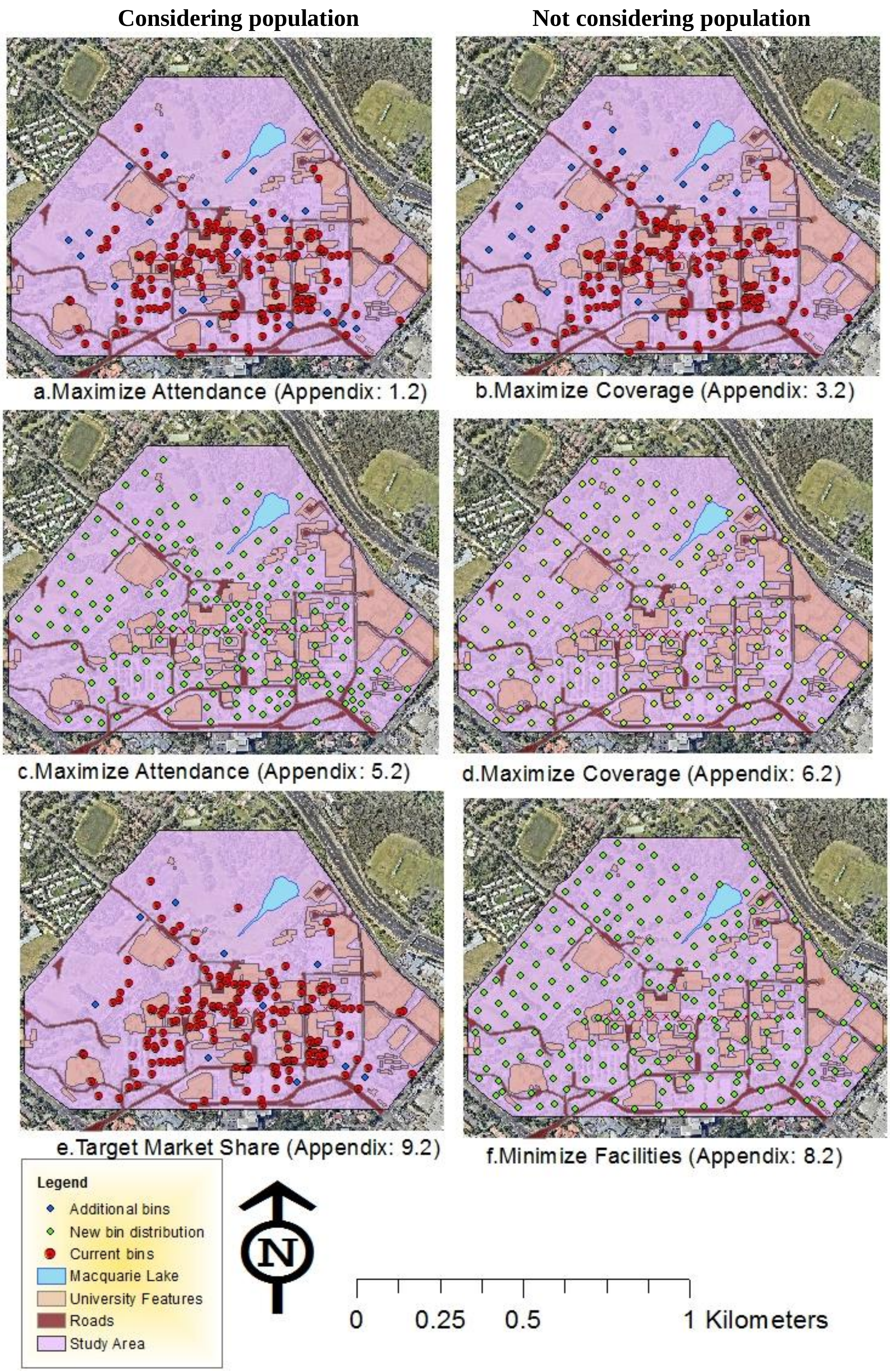

Figure 4.10: Distribution of bins at 52 meter impedance cut-off in problem types that incorporate population (number of bins: a=214, c=194 and e=109) and problem types that do not incorporate population (number of bins: b=214, d=194 and f=101).

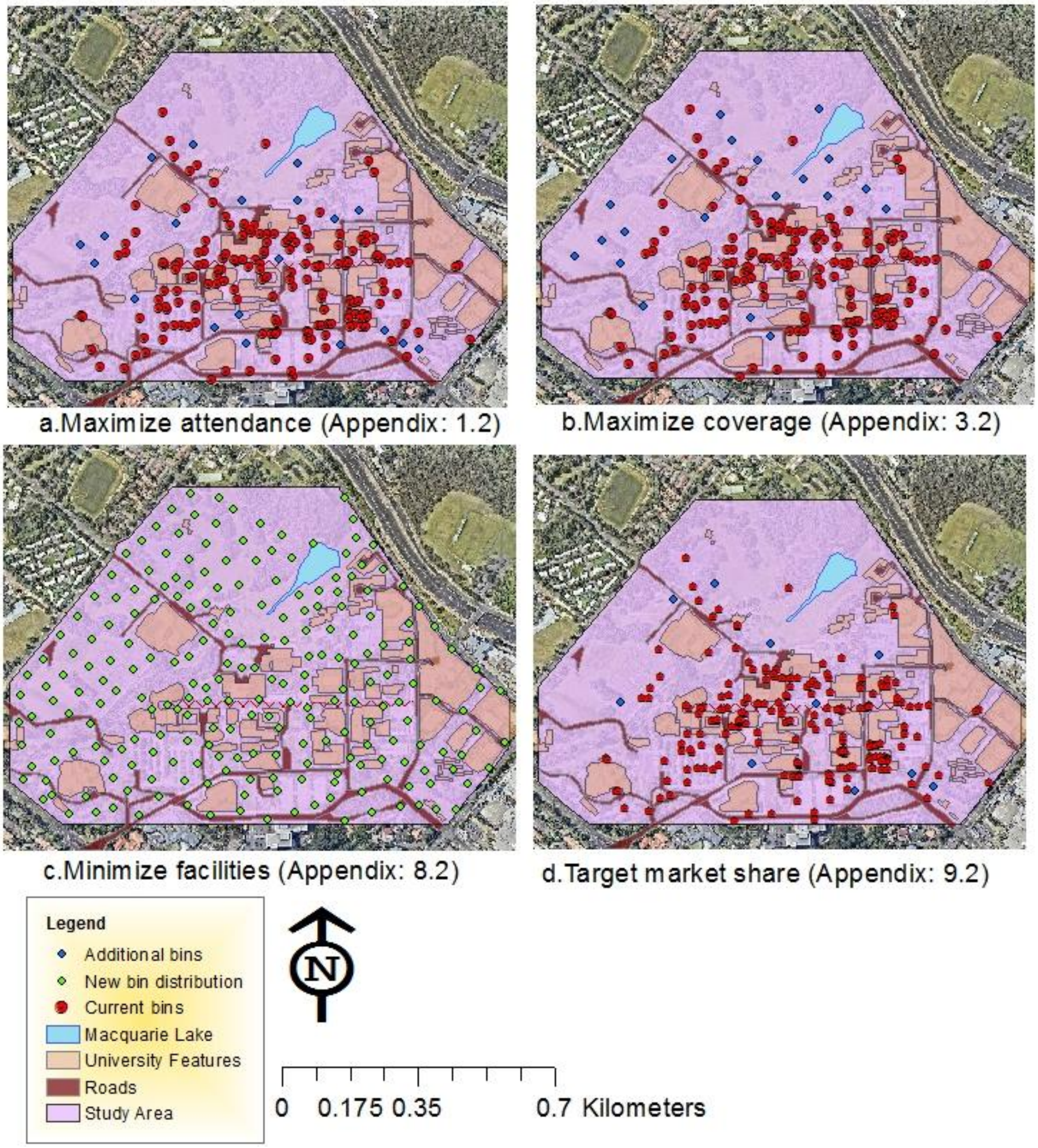

Figure 4.11: Optimizing location of additional bins considering various problem types at 52 meters impedance (number of bins: a=214, b=214, c=227, d=204).

Chapter 5: Discussion and Conclusion

This final chapter provides a discussion of my investigation, analysis and presents results and conclusions. The chapter begins by explaining the importance of public opinion for optimizing the location of public litter bins. It then discusses the impact of preferred walking distance to bins and location allocation problem types on the optimization outputs. Finally, it explores the implications of this study for the waste management sector. Limitations of the research are briefly outlined and recommendations for future research priorities are made.

Importance of user demand and public opinion for optimizing the location of litter bins

I found that currently litter bins were concentrated in high population density areas, especially the central region of the Macquarie University study area (Figure 5.1). However, moderate population density areas (e.g. between the library and building E3B, and the areas adjacent to the Hearing Hub, Campus Hub, and buildings F9B and X5A), had very few or no litter bins (Figure 5.1). This indicates that the spatial allocation of litter bins at Macquarie University probably needs adjustment to more adequately meet user demand or expectations.

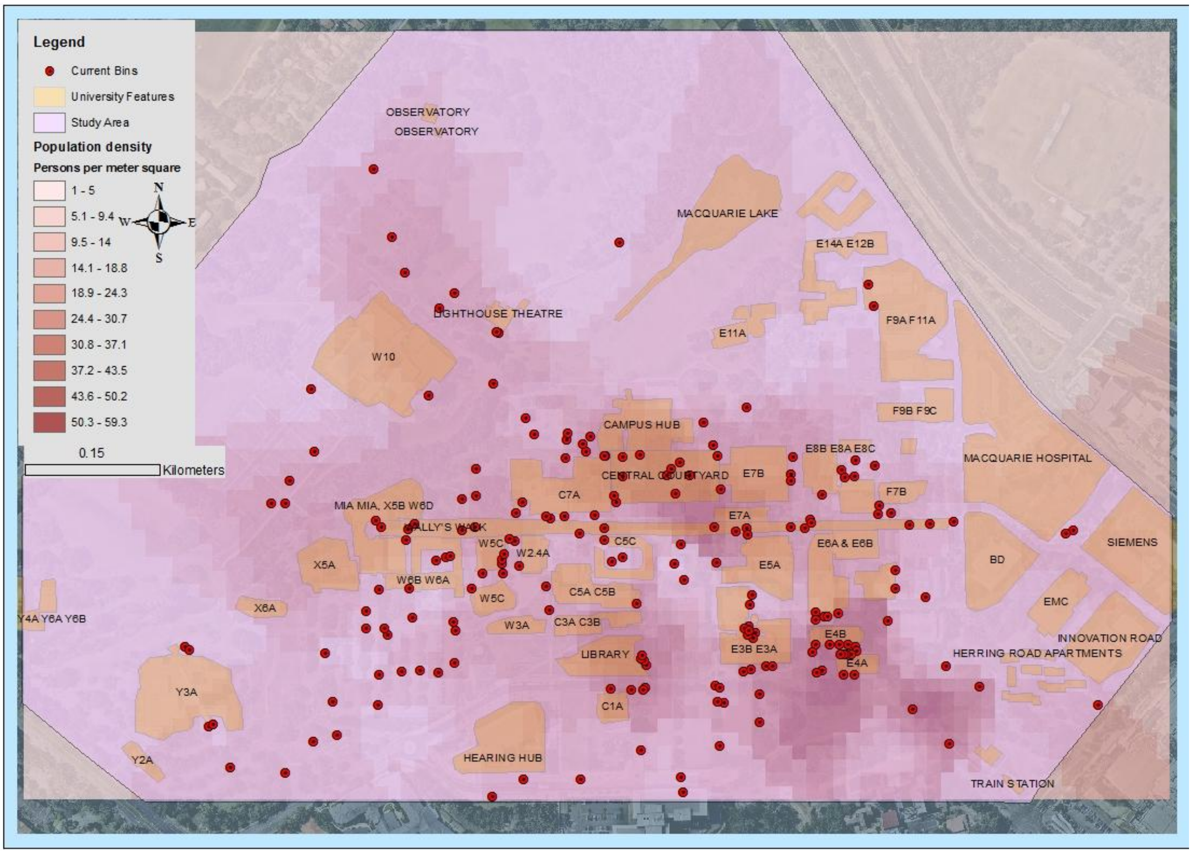

Figure 5.1: Relationship between population density and current bins in Macquarie University.

Previous studies show that including public preferences on the distance between litter bins assists in building consensus and reduces disputes and conflicts between waste management authorities and public users (Higgs, 2006). My investigations incorporated public preferences, by utilizing a survey tool to elucidate attitudes towards litter and opinions on maximum walking distances between bins from 200 users. The information on preferred walking distances informed the development of multiple scenarios for the optimization and spatial allocation of public litter bins at Macquarie University (Tables 3.2 - 3.5). As noted in Chapter 2, Kao and Lin (2002) used maximum acceptable walking distances of between 50 - 100 metres, but did not base these distances on evidence. Contrary to Kao and Lin (2002), I used five maximum walking distances (38m, 52m, 63m, 80m, and 400m), which were the result of a user survey. Eliciting the opinion of users enabled me to define the impedance values for my optimization analyses and increased the confidence in the modelling outcomes.

Sixty-one survey participants believed that littering was a result of laziness. Survey participants also thought that increasing the number or relocating bins help in reducing litter events in addition to other incentives, including education and awareness campaigns. Previous studies find that regular incentives and awareness campaigns influence environmental behaviour in a positive way (Eastman, *et al.* 2013). Prompts and information also encourage positive attitudes towards litter management (Garces, *et al.* 2002). The survey participants in my study supported environmental education campaigns, which is consistent with other research showing education is a litter solution (Kollmus and Agyeman, 2002; Santos, *et al.* 2005). This is also supported by Tonglet *et al.* (2004) who argues that level of awareness among users is a key factor in litter management.

The results from my thesis are comparable to research by Eastman *et al.* (2013) and Santos *et al.* (2005) even though their studies are based on beach environments (Table 5.1). The most preferable solution of users in Eastman *et al.* (2013) and Santos *et al.* (2005) was environmental education. I found that adding bins was also preferable to 131 survey participants. However, this might be because participants were allowed to choose multiple solutions in my survey. Being forced to choose only one solution may have provided different results. Survey participants thought an integrated approach was necessary, where a combination of solutions are implemented, including adding more bins, environmental education, fines, maintaining cleanliness of environment by management, keeping bins clean and putting lids on them, and for users to exhibit personal responsibility. Fines and maintaining cleanliness were among the top four solutions identified by the previous studies of Eastman *et al.* (2013) and Santos *et al.* (2005).

Table 5.1: Preference of solutions in the present study

Solution	Present Study (number of responses)	Eastman *et al*. (2013) (proportion of responses %)	Santos *et al.* (2005) (proportion of responses %)
Add number of bins	131	11.2	36.7
Environmental education	62	30.7	42.6
Strict rule e.g. fine	19	24.8	7.7
Maintain cleanliness	4	13.4	4.1

This study supports the findings of previous research that has shown that factors in addition to walking distance, such as cultural attitudes of users (Schulz et. al. 2013), bin attributes (size, opening mechanisms, visibility, hygiene) cleaning frequency, relationship with security, CPTED (Crime Prevention Through Environmental Design) (Tseng, et. al. 2004) (Figure 4.5). Therefore, it is necessary to develop an integrated approach to reduce litter at an enterprise scale by both optimizing the location of bins and integrating the behavioural and attitudinal aspects of community.

Impact of impedance (i.e. preferred walking distance) on the spatial allocation of bins

The distance that users need to walk to public litter bins is a strong predictor of littering behaviour (Liu and Shibley, 2004). To understand the variation in spatial allocation of bins under different impedance values, I used five preferred walking distances in my optimization analyses. Increasing the impedance value had the effect of increasing the distance between bins in all of the network analysis' location allocation problem types. In addition, increasing the impedance value also had the effect of reducing the number of litter bins in those scenarios and problem types where a fixed number of bins was not provided (Table 3.4).

The lowest impedance value we used in our analysis was 38 meters. This was in contrast to Scultz *et al.* (2013) who stated that litter bins should be placed at a distance of less than 7 meters apart to achieve the lowest rate of littering. Allocating bins at a distance of less than 7 meters would be very expensive in a large region such as Macquarie University. By combining user preferences with a network analysis, we were able to come up with a range of options, from low cost (e.g. 400 metres) to higher cost (e.g. 38 metres) for managers of waste on the campus to consider

Impact of network analysis problem type on the spatial allocation of bins

The survey with users found that 70% of respondents thought that increasing the number of bins would help reduce litter in the study area (Table 5.1). In lieu of this result, Scenario 1 (*Adding more* *bins to meet demand and user preferences whilst retaining the current location of bins*) was used to allocate additional bins to the study area. I used both the maximize attendance and maximize coverage problem types for the analysis to add 20 and 39 bins to the current bin distribution. The differences between the outputs of the two problem types (e.g. Appendix Figure 1.1 vs. 3.1) were because the maximize coverage problem type does not incorporate population demand. Therefore, the maximize coverage problem type is only effective when population density is homogenous across the study area or when cost is not a limiting factor (and impedance value is low). For example, locating bins in the remote northern region of the campus (e.g. Appendix Figures 3.1 – 3.5), where population demand was very low (Figure 4.3), increases cost to management as bins would need to be collected over a very wide area. Schultz *et al.* (2013) found that a well-placed litter bins are more likely to reduce the amount of litter than several inconveniently placed bins. Therefore, it is essential that litter bins are located where there is high demand using problem types such as maximize attendance. The maximize attendance problem type has the additional benefit of being able to allocate bins to currently missed high density areas or medium density areas (e.g. Appendix Figures 1.1 – 1.5; 2.1 – 2.5). This problem type is hence relevant for managing litter within a limited budget.

A small number of survey respondents thought that relocating bins would help reduce litter in the study area (Table 4.1). Scenario 2 (*Redistributing the current number of bins to meet demand and user preferences*) was used to redistribute the current number (194) of bins across the study area. I used the maximize attendance, maximize coverage and minimize impedance problem type in this scenario. Similar to Scenario 1, the maximize coverage and minimize impedance problem types resulted in a uniform distribution of bins in the study area (Appendix Figures 6.1 – 6.5 and 7). The spatial allocation of bins was more concentrated towards highly populated areas when using the maximize attendance problem type (Appendix Figures 5.1 – 5.5). A potential issue associated with the maximize attendance problem type is that when the impedance value is low (e.g. 38m), bins were not allocated to areas of low population density (Appendix Figure 5.1). A consequence of using this problem type is an increase in litter in low population density areas.

The problem types minimize facilities and target market share calculate the required number of facilities given an impedance value and, for target market share, population demand. These problem types are most relevant to situations where there is uncertainty about how many litter bins are required. The major difference between the two problem types is that minimize facilities do not consider population demand or the current location of bins, and instead aims to allocate bins to achieve the greatest coverage within a given impedance value. The target market share problem type is more appropriate to use in situations where managers are seeking to add a minimum number of bins to the current bin distributions to meet population demand. This problem type would therefore benefit enterprises that are undergoing redevelopment or expansion at some locations, causing a redistribution of population demand across the region.

This study suggests that for an enterprise scale, the most preferable distance between litter bins is between 38 and 80 meters. Table 5.2 indicates the combination of preferred walking distance and scenarios that are most likely to reduce littering at Macquarie University (Table 5.2).

Table 5.2: Number of bins optimized under multiple scenarios, and the estimated likelihood of the scenario reducing littering in the study area. Walking distances and scenarios highlighted in green are the most likely to results in littering, yellow moderately likely, and red least likely

	Scenarios												
Walking distance (meters)	*Adding bins*				*Relocating bins*			*Optimizing bins at low cost*			*Reducing number of bins*		
	Maximize attendance		Maximize coverage		Maximize attendance	Maximize coverage	Minimize impedance	Minimize facilities	Target Market Share		Maximize attendance		
	10%	20%	10%	20 %					10%	20%	10%	20%	
38	214	233	214	233	194	194	194	398	206	225	174	155	
52	214	233	214	233	194	194		227	204	217	174	155	
63	214	233	214	233	194	194		161	203	214	174	155	
80	214	233	214	233	194	194		109	201	211	174	155	
400	214	233	214	233	194	194		11	201	214	174	155	

Implications for waste management at Macquarie University

My analysis revealed a need for more bins behind the library, between the library and building E3B, between the Campus Hub and lake, at the car park behind W10, along the walking route between the train station and E4A, and between the Hearing Hub and C1A. I also found potentially unnecessary duplication of bins around the library, and buildings E3A, E8A, E8C, E4B, E4A, W5C and W6B (Appendix Figures 11.1 - 11.5 and 12.1 - 12.5). For example, there are currently 6 bins of 240L behind the buildings E3A and E3B (Figure 4.1), which are very close together and could be removed from the area. However, the rate of use of bins should be studied in order to understand the capacity of bins by systematically observing bin usage. My research suggests that several strategies are required to reduce litter in the study area. Survey participants suggested environmental education, fines and maintaining cleanliness as solutions for litter management (Figure 5.2). I recommend an integrated solution for litter reduction that moves duplicate bins to high demand areas, and that incorporates solutions suggested by users.

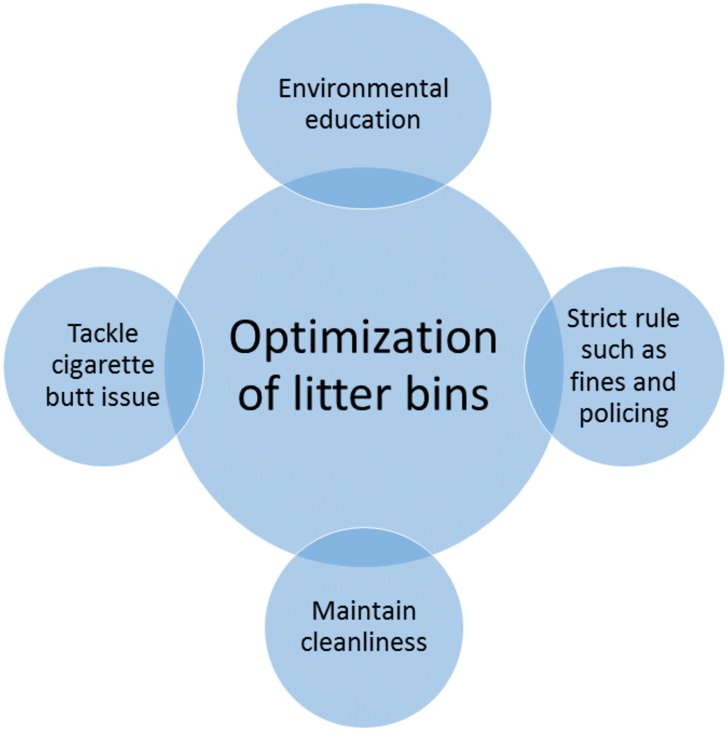

Figure 5.2: User's preferred solution to manage litter issue

Limitations of the study and future research

I performed a detailed optimization of litter bins under multiple scenarios within the study area of Macquarie University (Tables 3.2 - 3.5). However, questions still remain as to whether Macquarie University is willing to increase the number of litter bins or relocate current bins. Due to time limitations, I was unable to share the results of my analysis with the waste management team at Macquarie University prior to the submission of my thesis. Therefore this study was only able to incorporate user option and not the decision maker's perspective into the optimization. However, the purpose of running four scenarios, and multiple problem types and impedance values (n = 56 solutions) was to provide managers with a complete range of options to consider. An interesting direction for future research would be an economic or cost-benefit analysis for setting up a new distribution of litter bins. This would enable managers to consider not only the cost of maintaining bins but also the cost of relocating bins in their decision making process.

Again, due to time limitations, I was unable to survey more than 200 users. Increasing the number of survey participants would provide more accurate results on attitude and opinion associated with litter and willingness to walk to bins. Similarly, a higher number of locations for the population count would have improved the output of the population density model (Figure 4.4). Future research would benefit from a comparative analysis between universities or other organisations at a similar scale. It would be particularly interesting to compare the outputs between suburban (e.g. University of Western Sydney) and city (e.g. University of Sydney) campuses as this could result in different perspectives on how far users are prepared to walk to a bin or their attitude towards litter.

Conclusion

My thesis provides integrated and optimized solutions for public litter bin managers to consider in their decision making process. The problem types maximize attendance and target market share are the most appropriate network analysis tools to use at the enterprise scale and when population density is heterogeneous. I found the most 'user friendly' and cost efficient distances people were prepared to walk to bins was between 38 and 80 meters. The approach I developed could be used to optimize the number and location of public litter bins at other locations and at a similar scale. My specific recommendations would be: to re-distribute more closely spaced bins to identified medium population areas, to possibly add more bins to the campus total; to implement integrated management strategies for litter reduction on campus.

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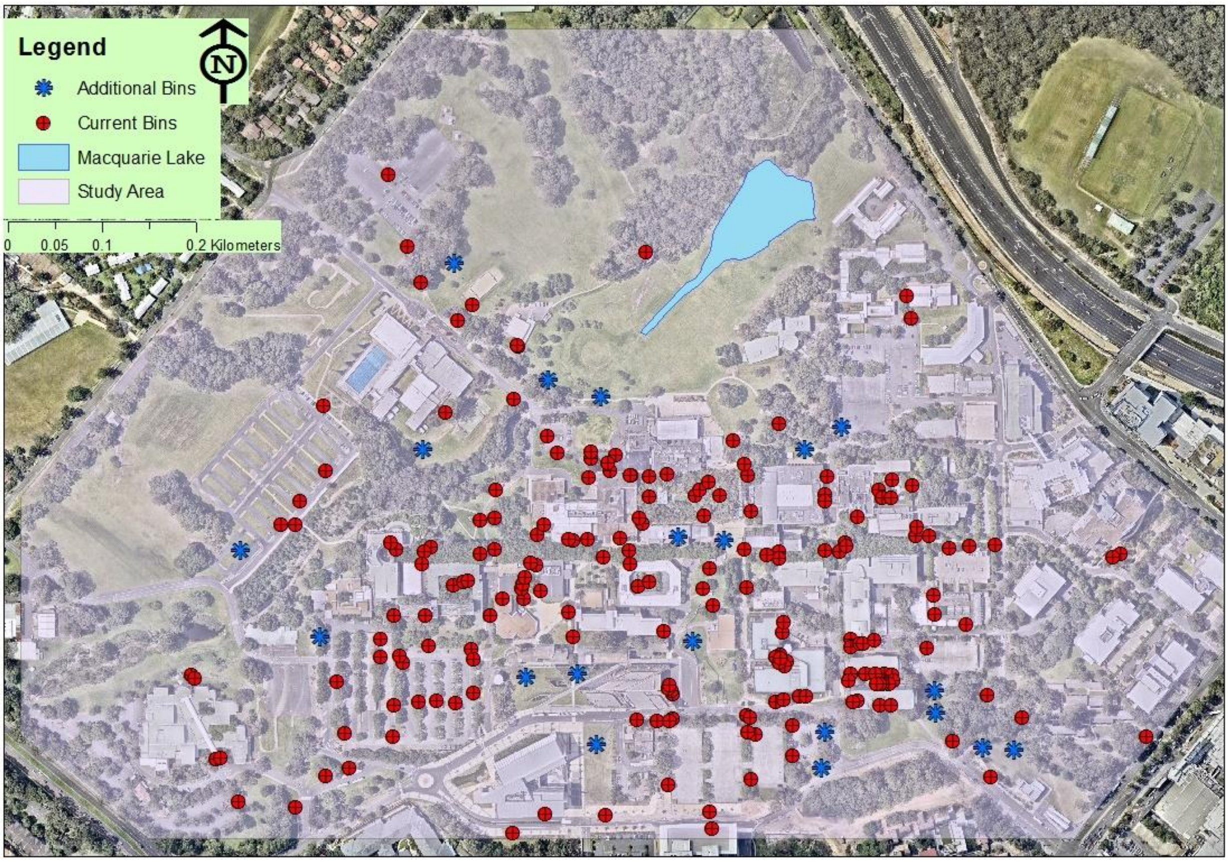
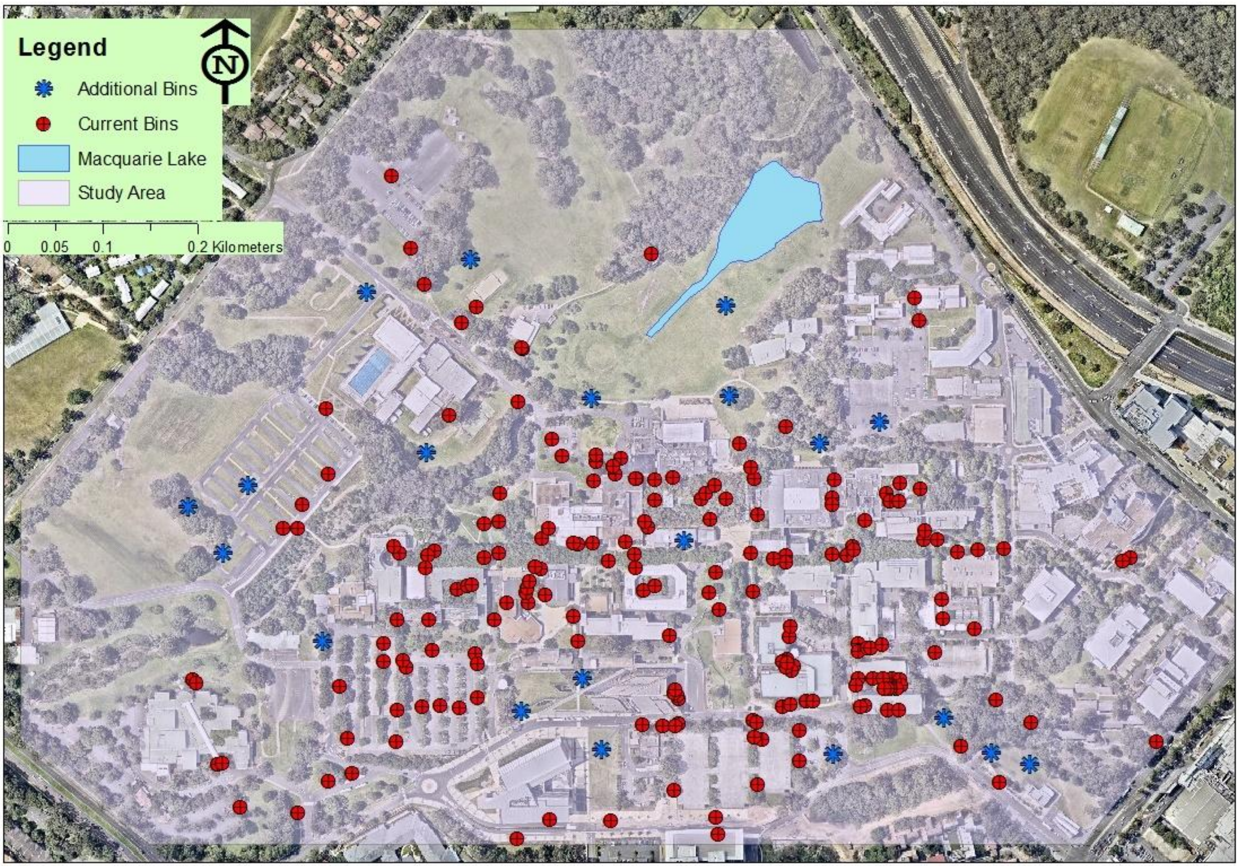
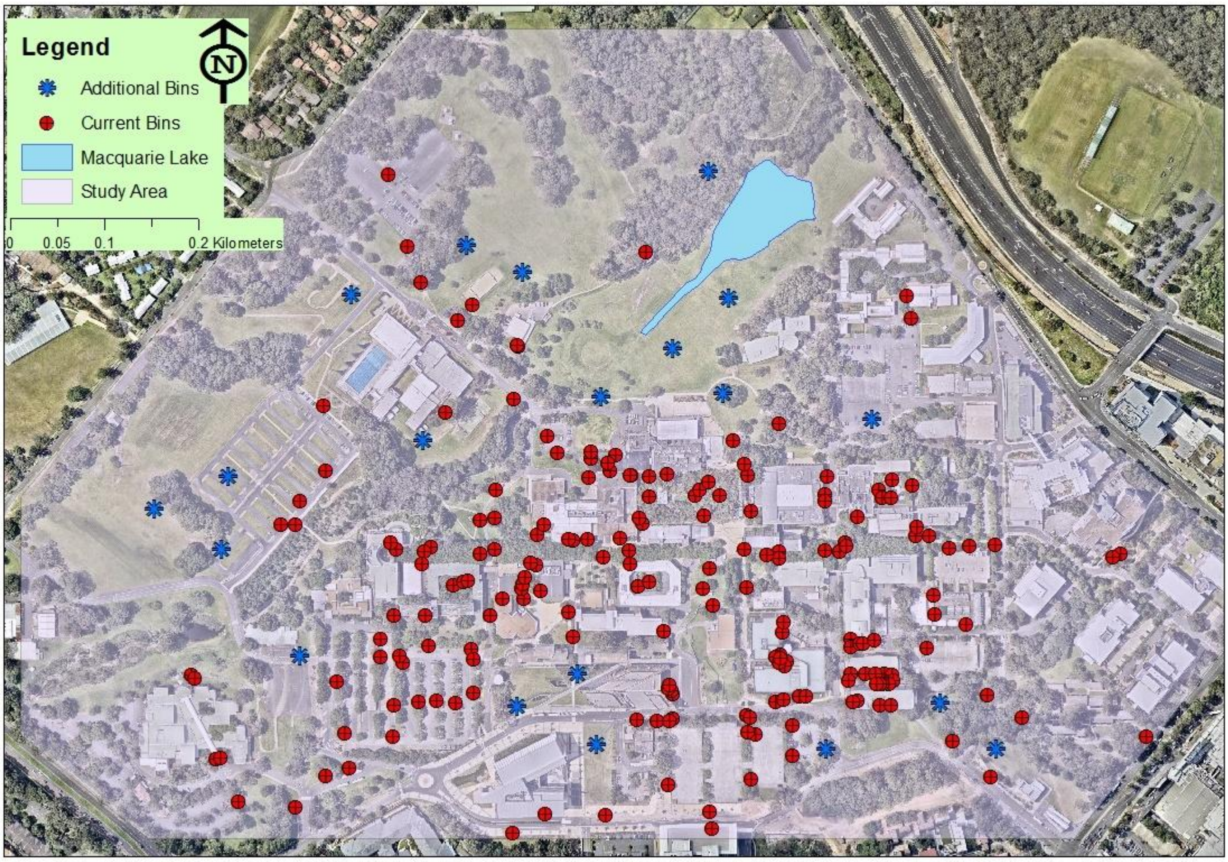
Appendix



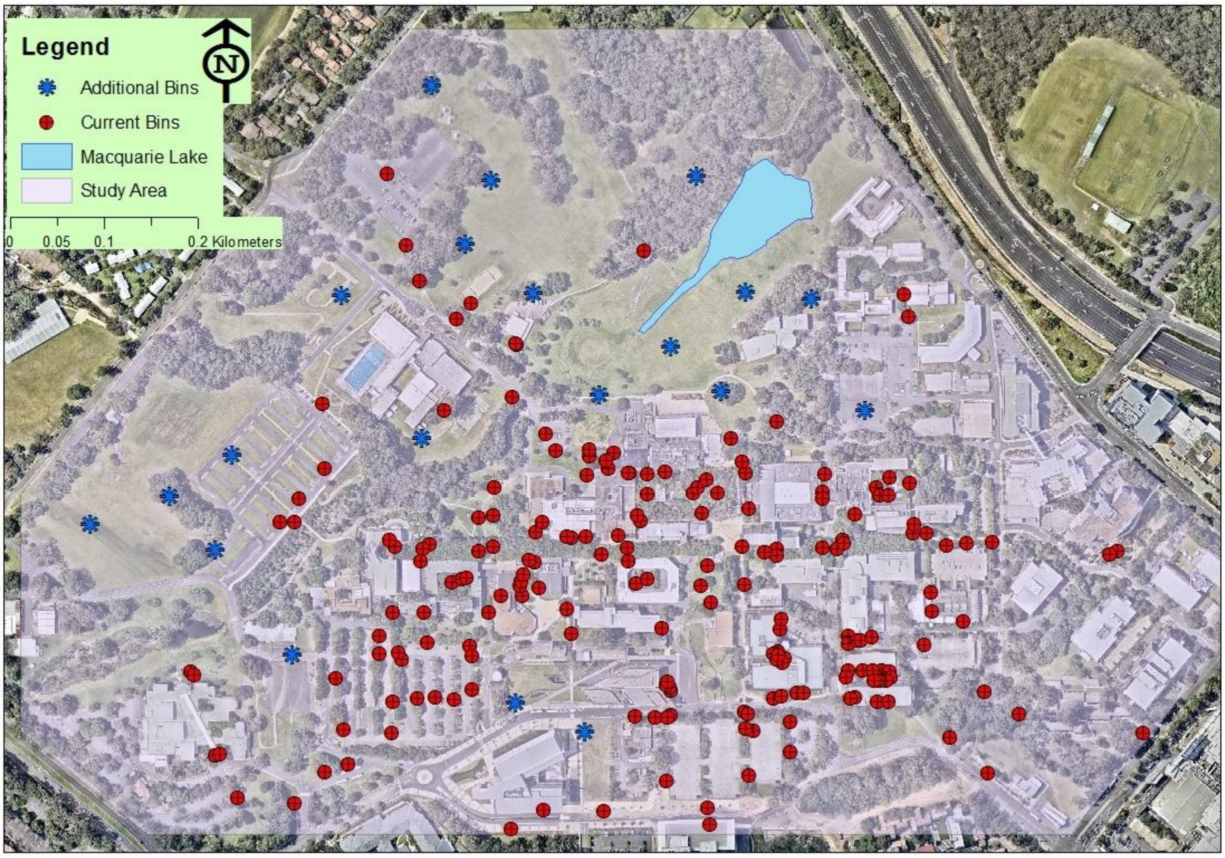
Appendix 1.1: Allocation of 10% of additional bins (20) to current distribution of 194 litter bins using 'maximize attendance' problem type and considering population density at 38 meter impedance cut-off



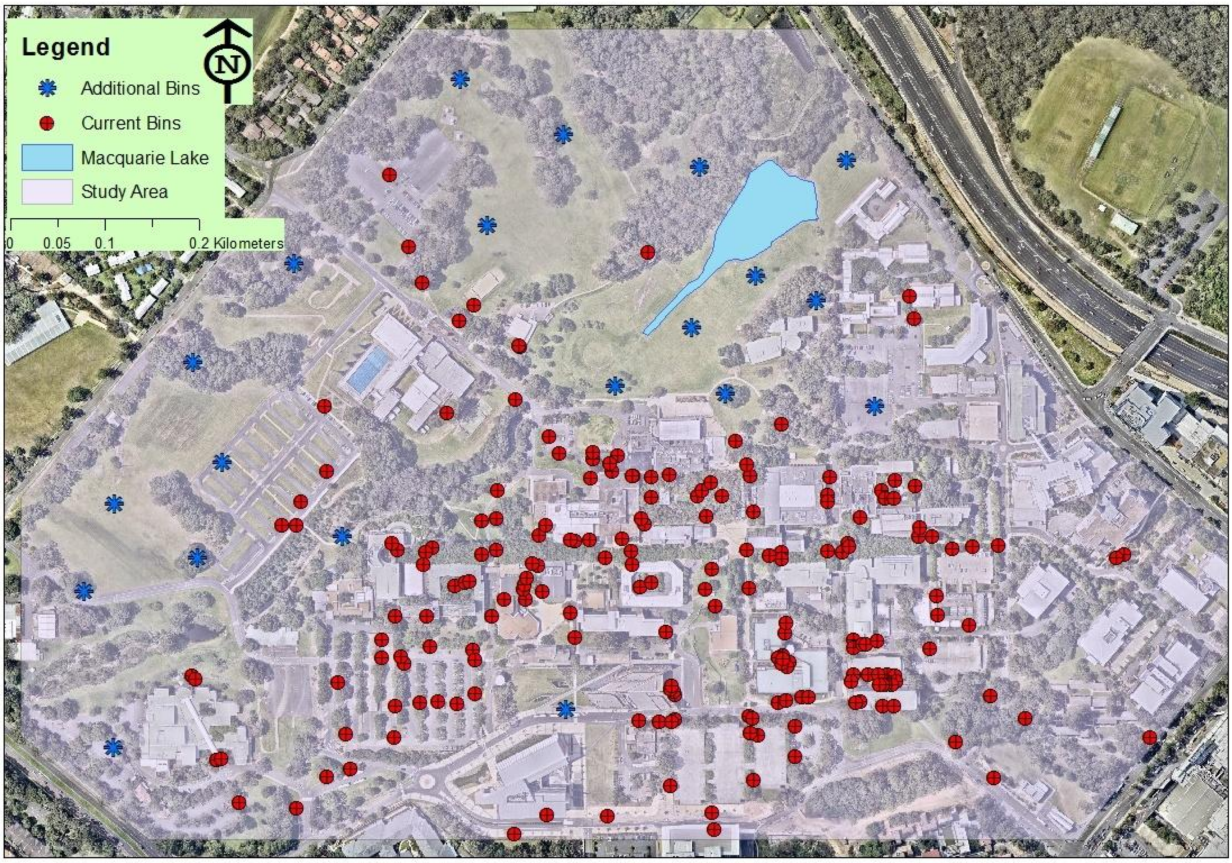
Appendix 1.2: Allocation of 10% of additional bins (20) to current distribution of 194 litter bins using 'maximize attendance' problem type and considering population density at 52 meter impedance cut-off



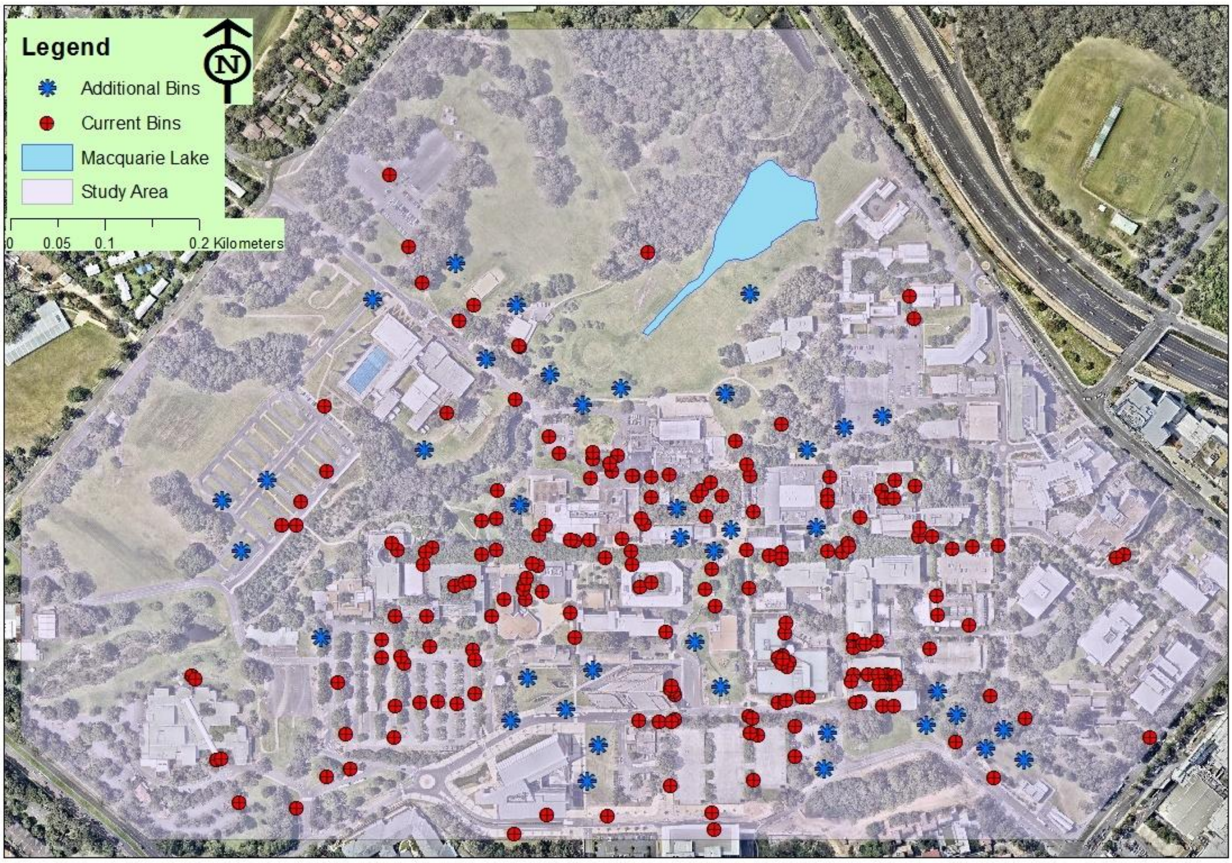
Appendix 1.3: Allocation of 10% of additional bins (20) to current distribution of 194 litter bins using 'maximize attendance' problem type and considering population density at 63 meter impedance cut-off



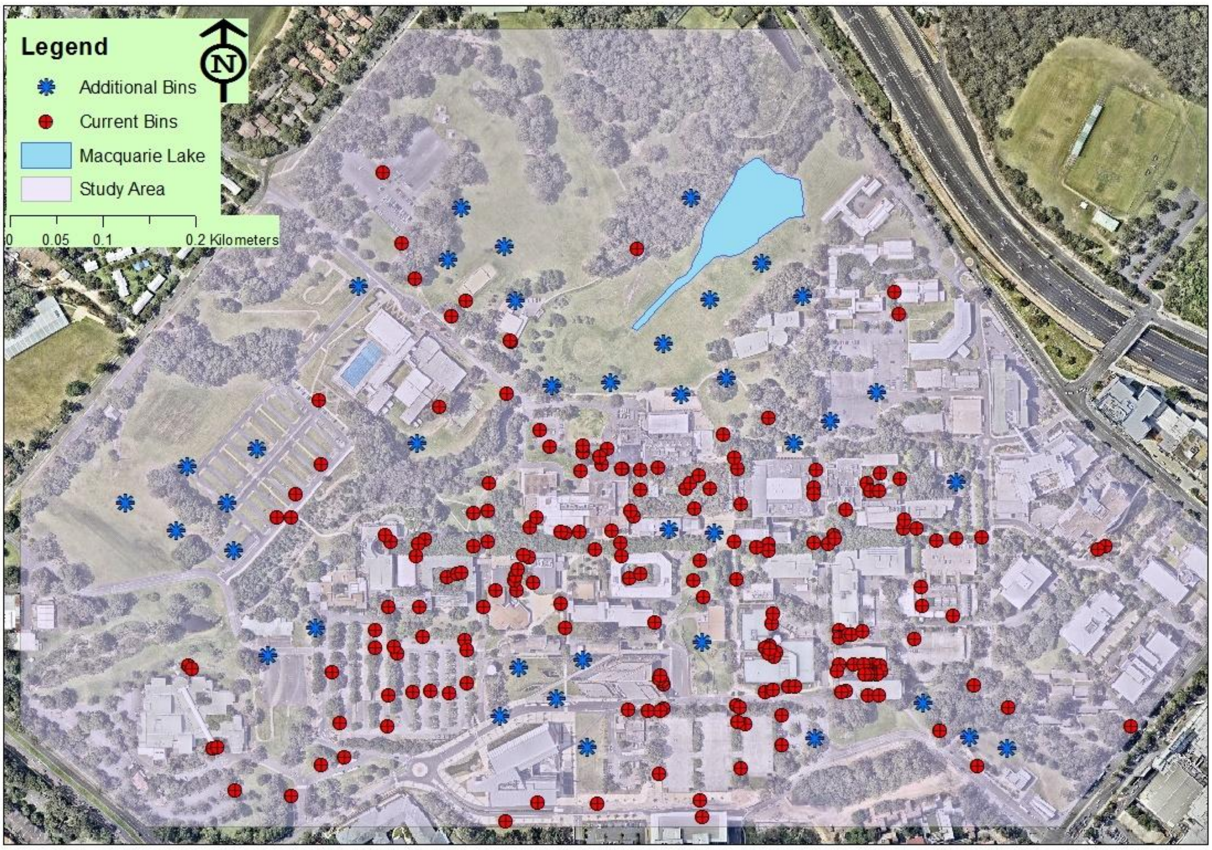
Appendix 1.4: Allocation of 10% of additional bins (20) to current distribution of 194 litter bins using 'maximize attendance' problem type and considering population density at 80 meter impedance cut-off



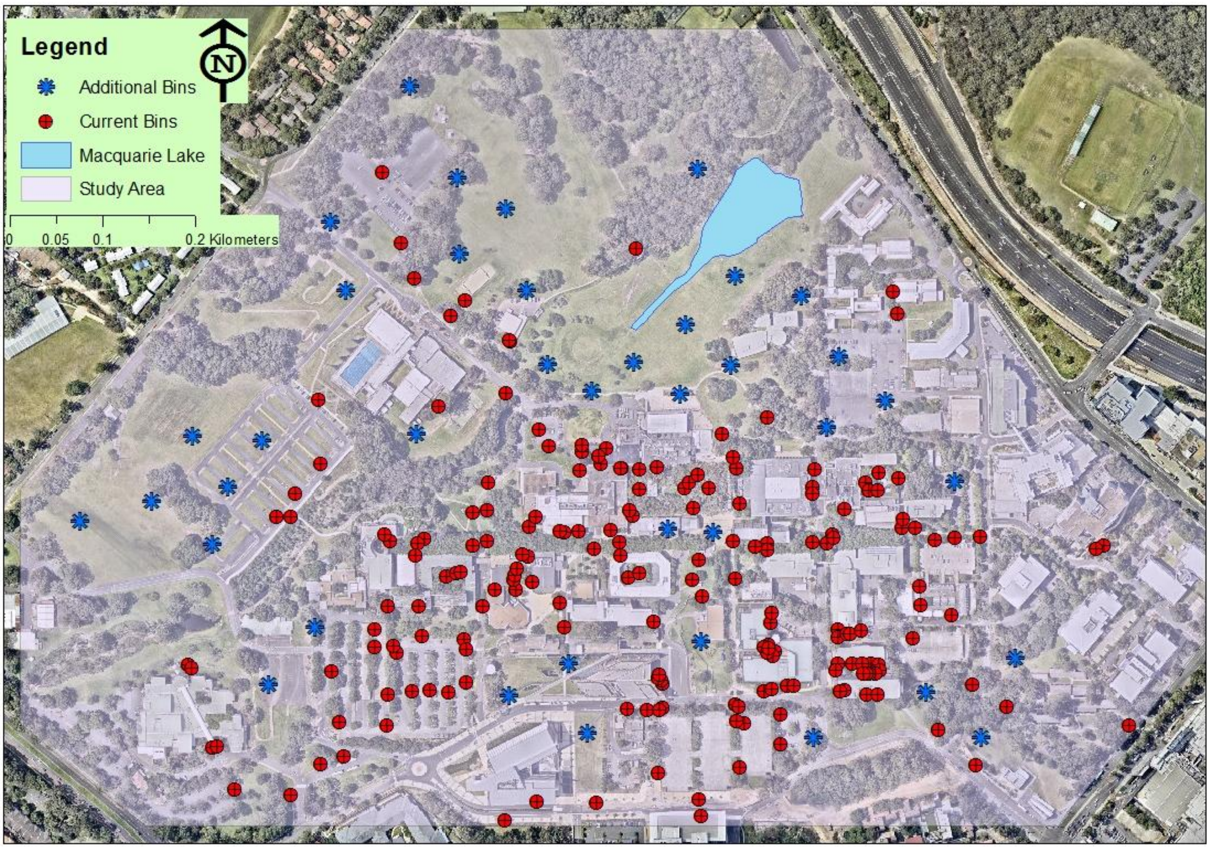
Appendix 1.5: Allocation of 10% of additional bins (20) to current distribution of 194 litter bins using 'maximize attendance' problem type and considering population density at 400 meter impedance cut-off



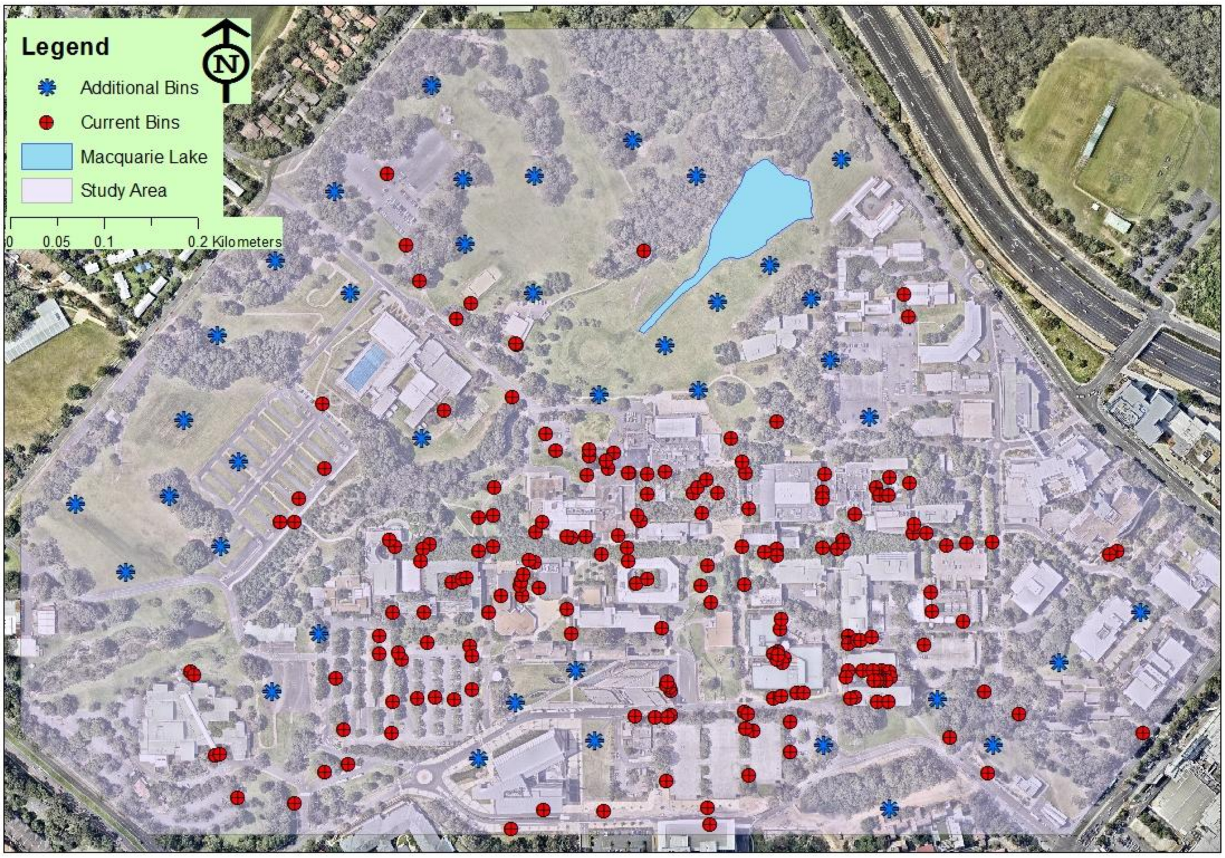
Appendix 2.1: Allocation of 20% of additional bins (39) to current distribution of 194 litter bins using 'maximize attendance' problem type and considering population density at 38 meter impedance cut-off



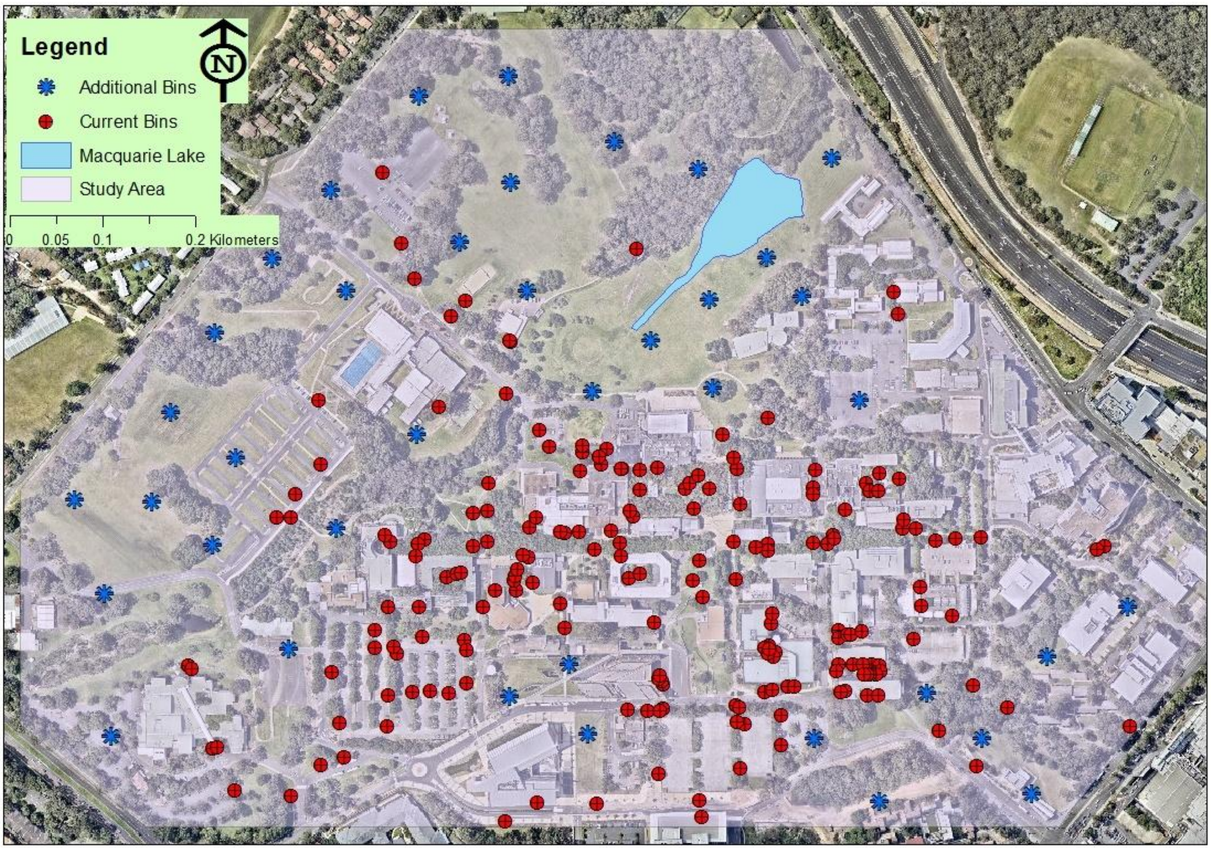
Appendix 2.2: Allocation of 20% of additional bins (39) to current distribution of 194 litter bins using 'maximize attendance' problem type and considering population density at 52 meter impedance cut-off



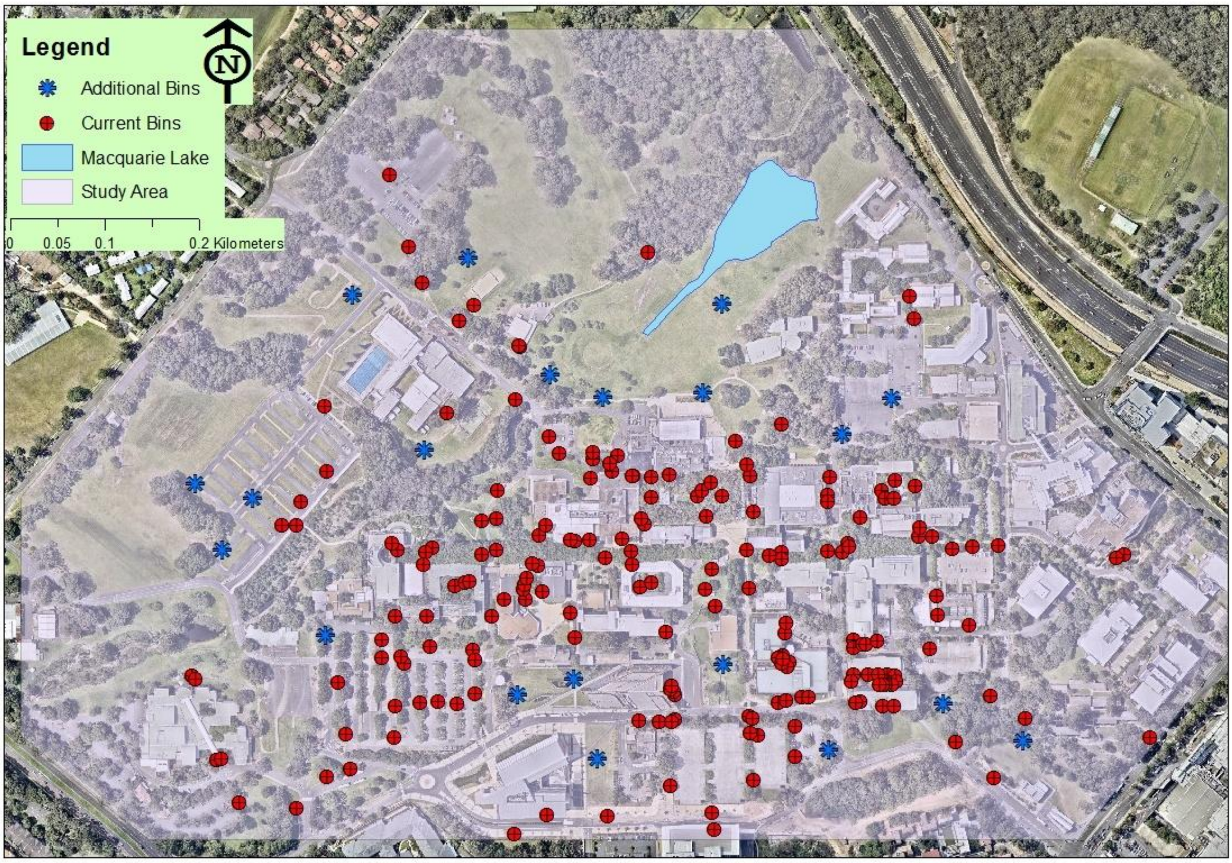
Appendix 2.3: Allocation of 20% of additional bins (39) to current distribution of 194 litter bins using 'maximize attendance' problem type and considering population density at 63 meter impedance cut-off



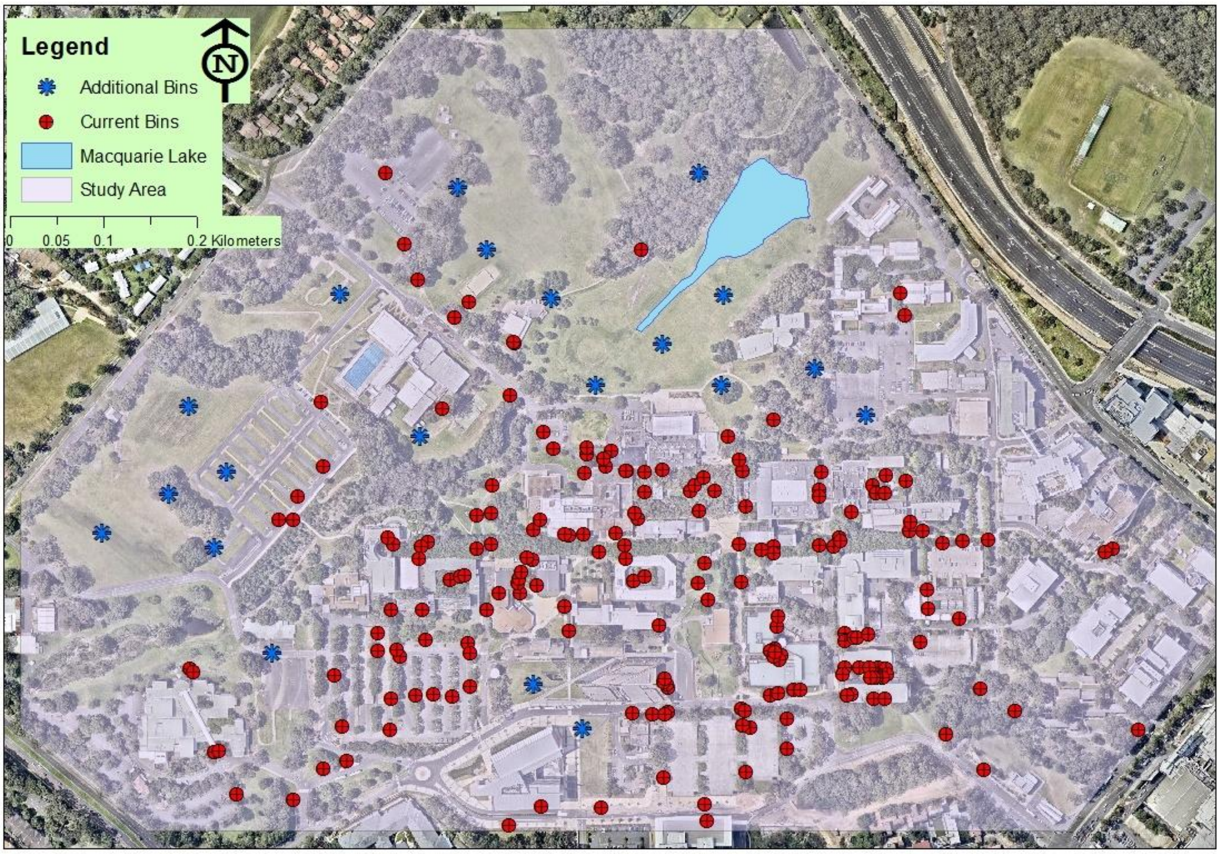
Appendix 2.4: Allocation of 20% of additional bins (39) to current distribution of 194 litter bins using 'maximize attendance' problem type and considering population density at 80 meter impedance cut-off



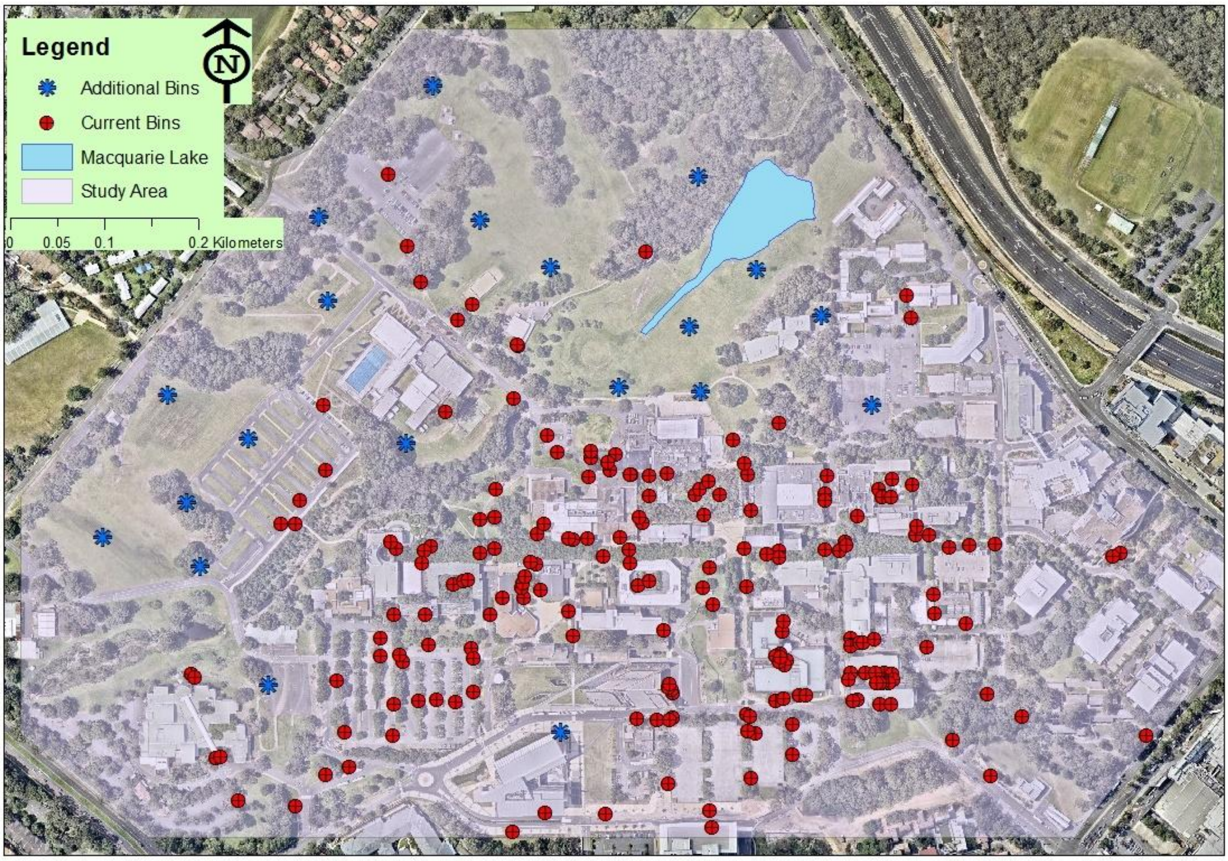
Appendix 2.5: Allocation of 20% of additional bins (39) to current distribution of 194 litter bins using 'maximize attendance' problem type and considering population density at 400 meter impedance cut-off



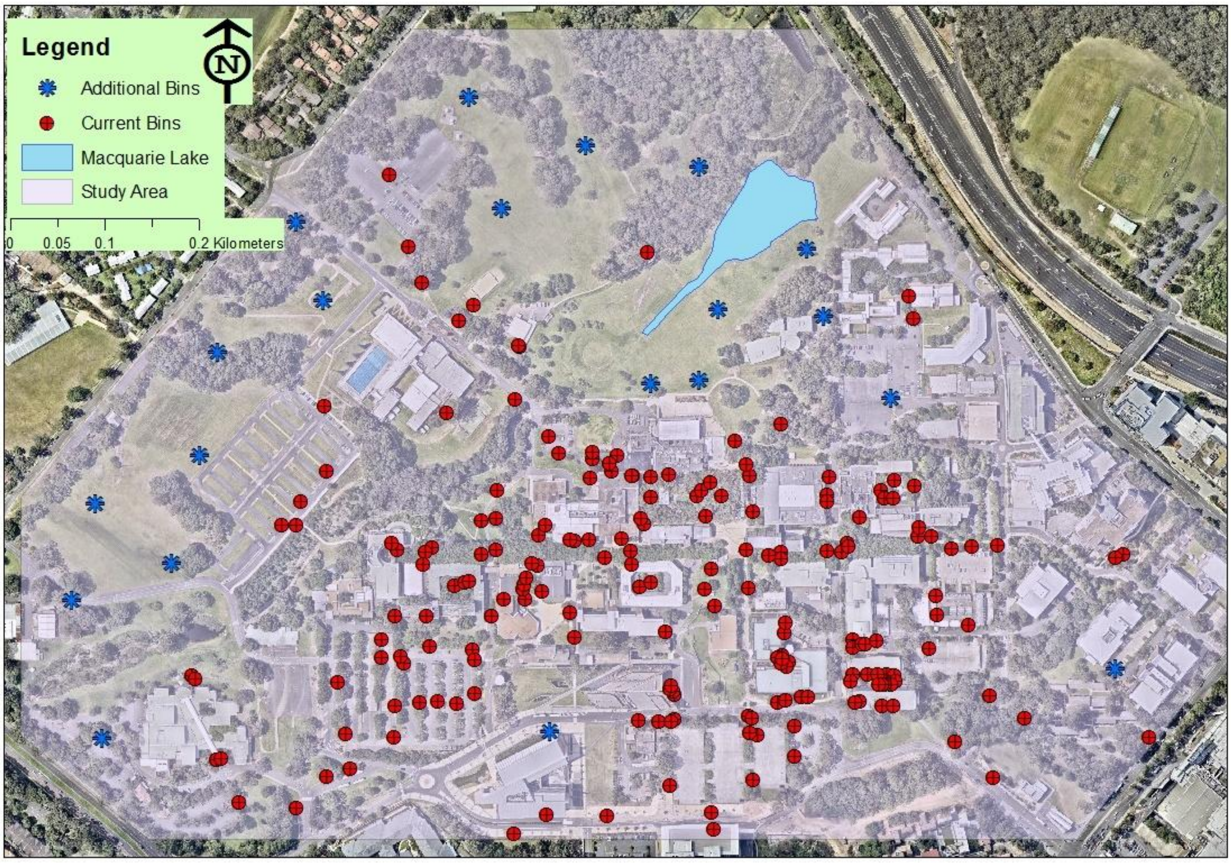
Appendix 3.1: Allocation of 10% of additional bins (20) to current distribution of 194 litter bins using 'maximize coverage' problem type but not considering population density at 38 meter impedance cut-off



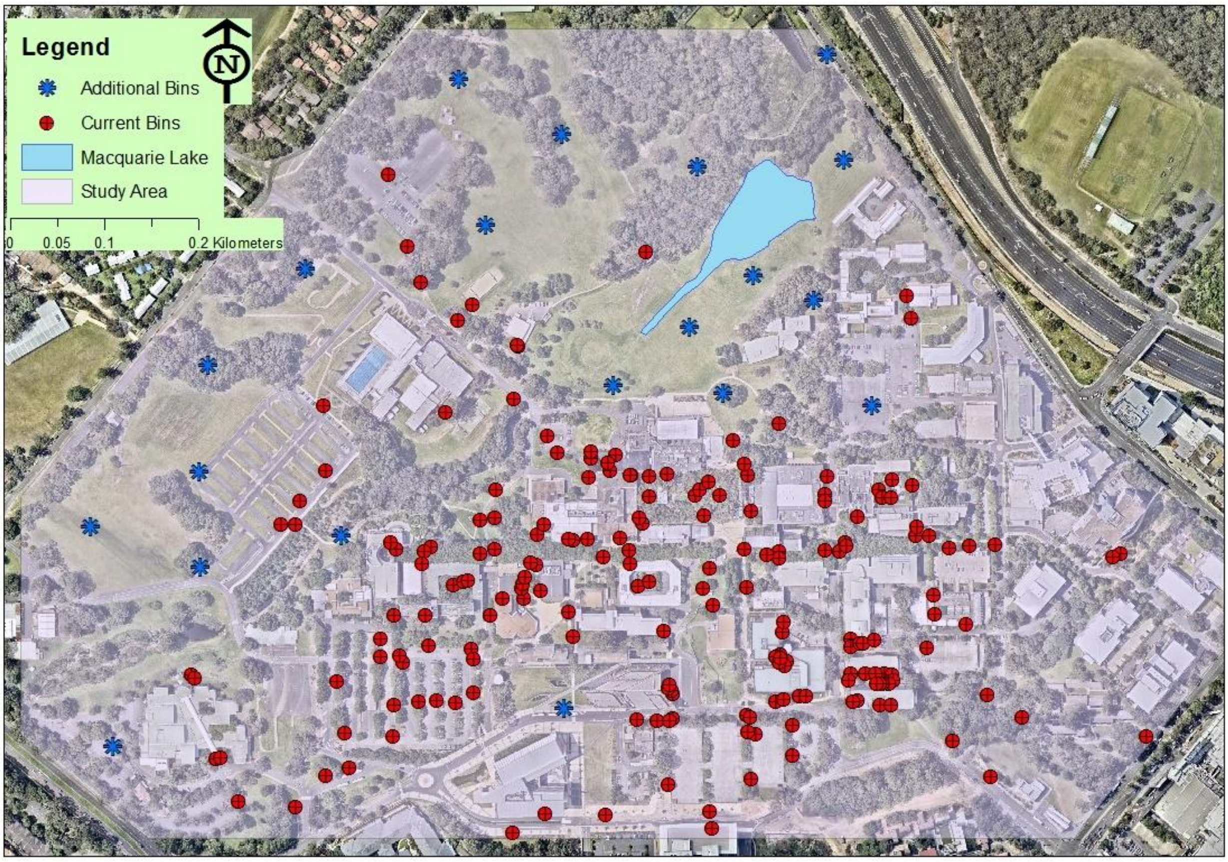
Appendix 3.2: Allocation of 10% of additional bins (20) to current distribution of 194 litter bins using 'maximize coverage' problem type but not considering population density at 52 meter impedance cut-off



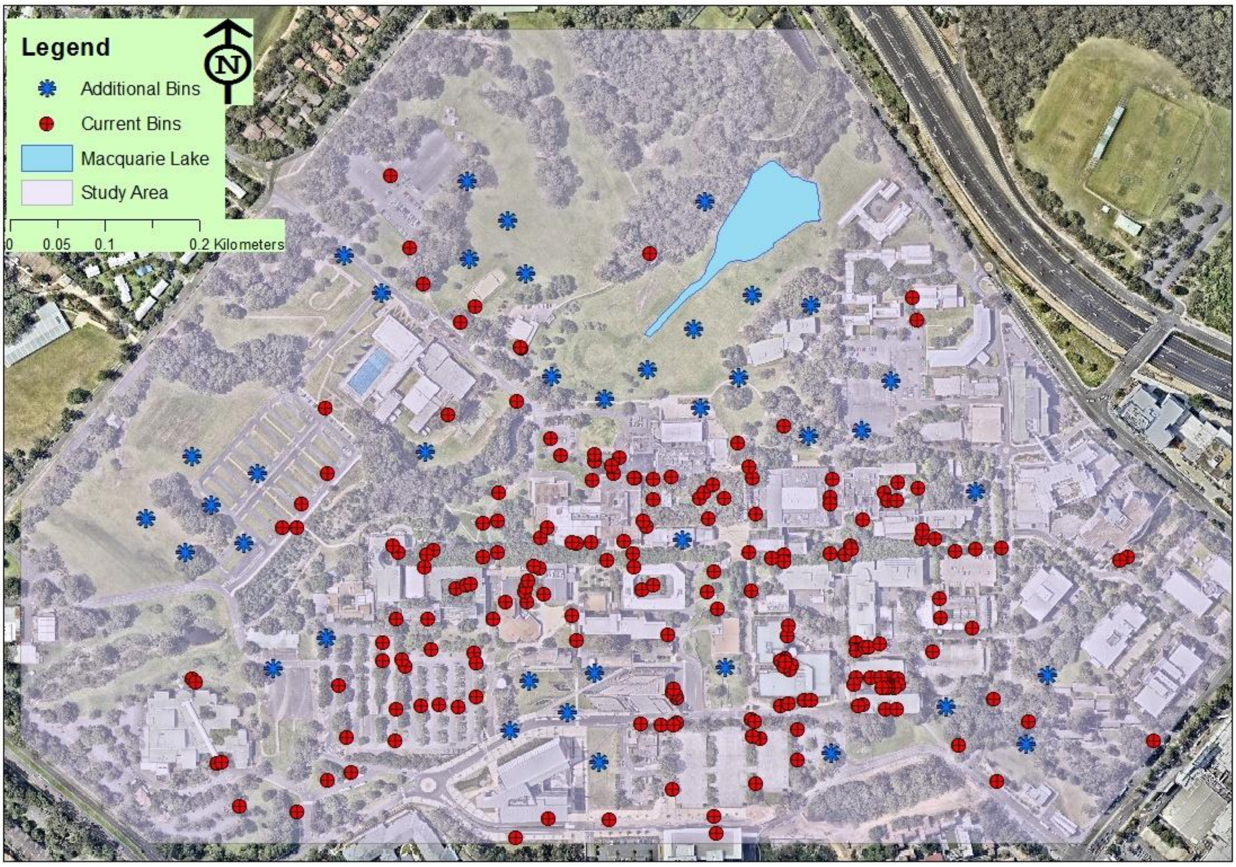
Appendix 3.3: Allocation of 10% of additional bins (20) to current distribution of 194 litter bins using 'maximize coverage' problem type but not considering population density at 63 meter impedance cut-off



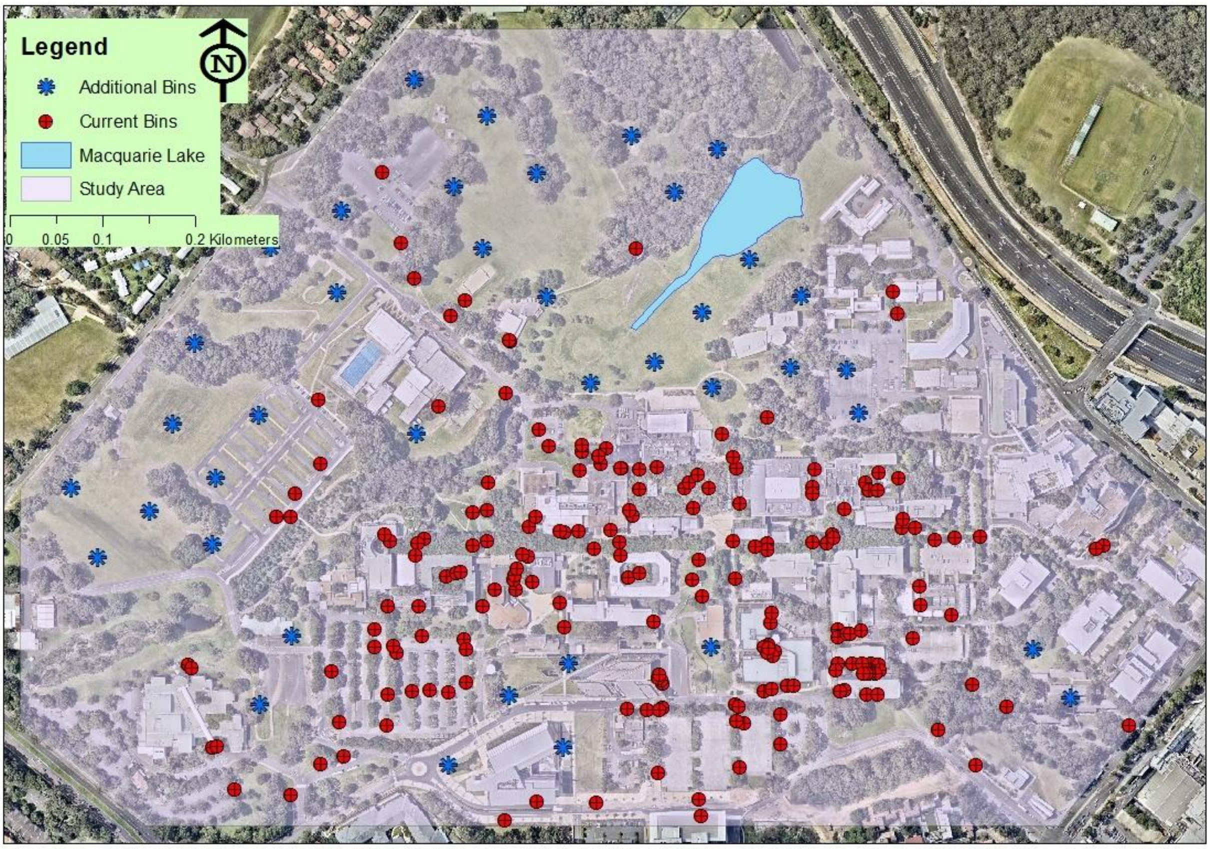
Appendix 3.4: Allocation of 10% of additional bins (20) to current distribution of 194 litter bins using 'maximize coverage' problem type but not considering population density at 80 meter impedance cut-off



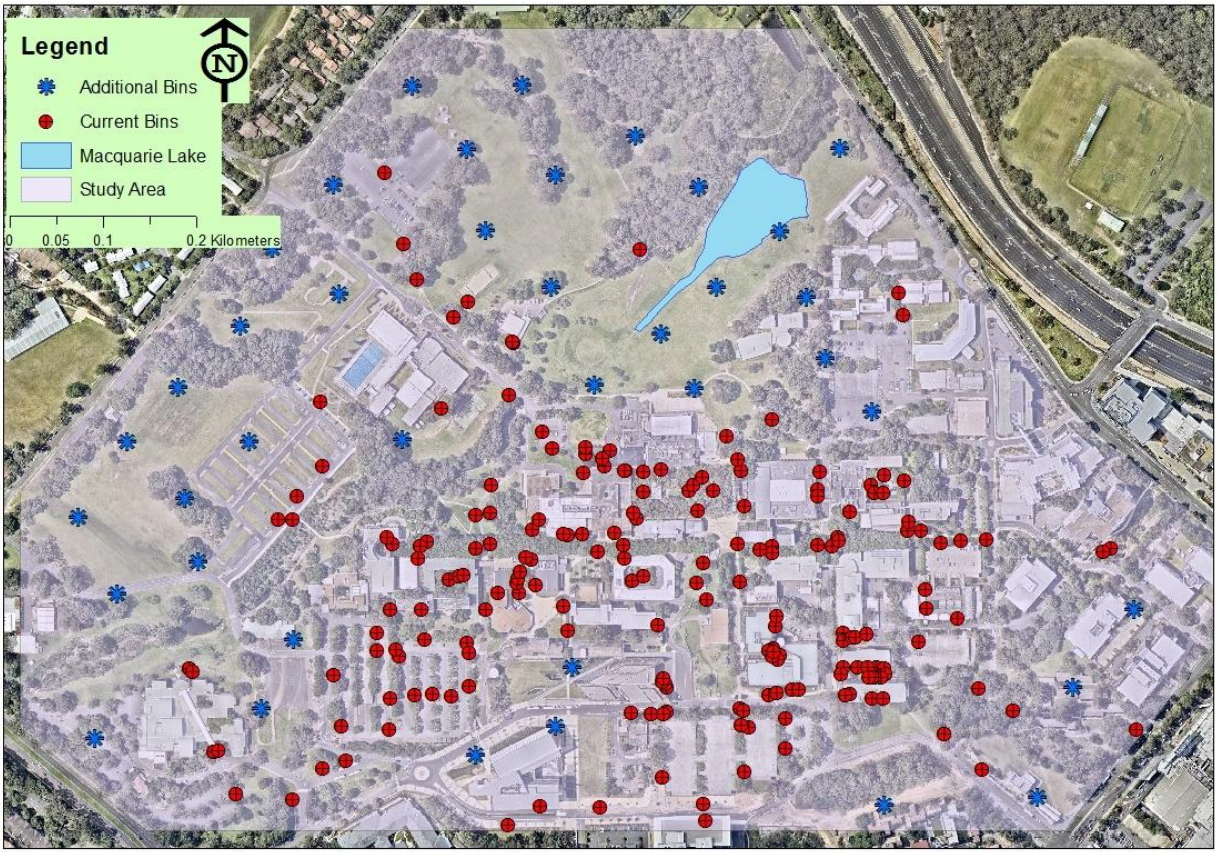
Appendix 3.5: Allocation of 10% of additional bins (20) to current distribution of 194 litter bins using ‘maximize coverage’ problem type but not considering population density at 400 meter impedance cut-off



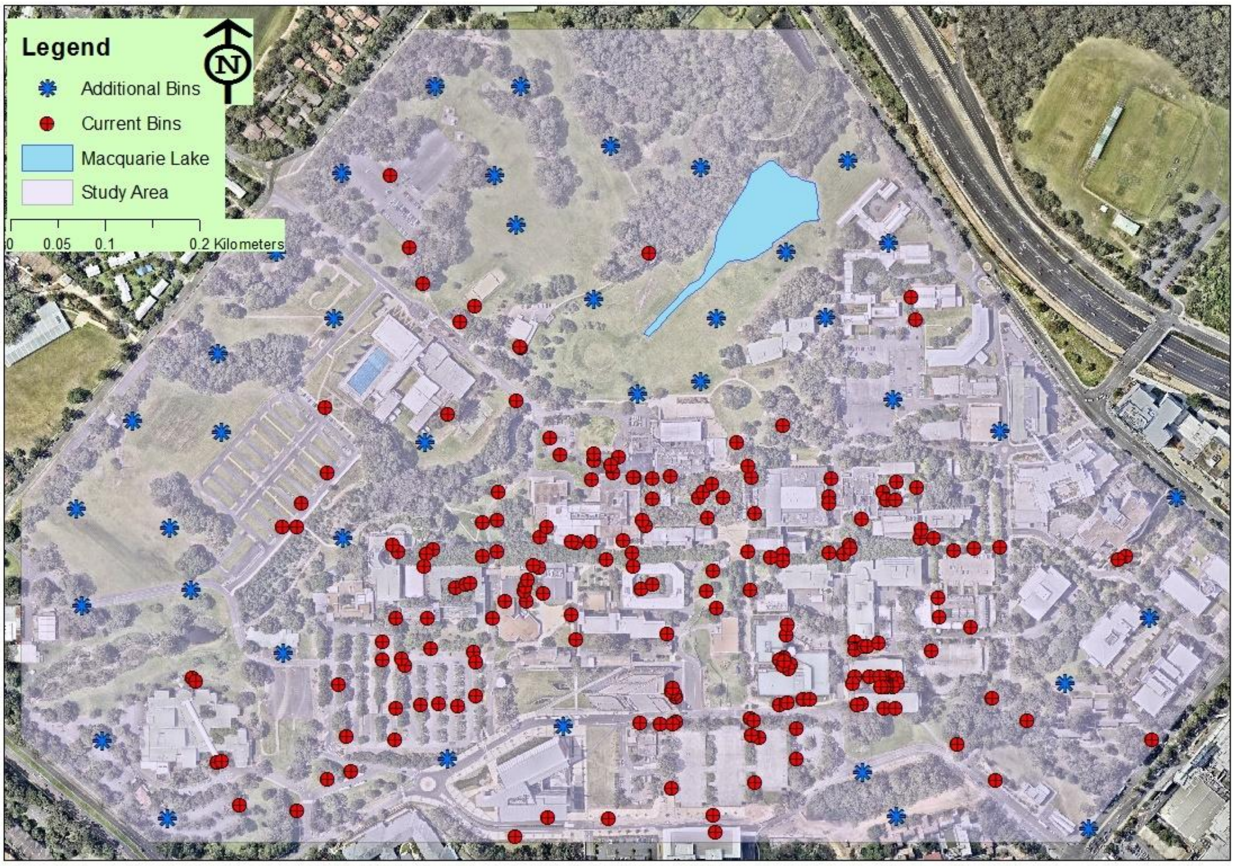
Appendix 4.1: Allocation of 20% of additional bins (39) to current distribution of 194 litter bins using ‘maximize coverage’ problem type but not considering population density at 38 meter impedance cut-off



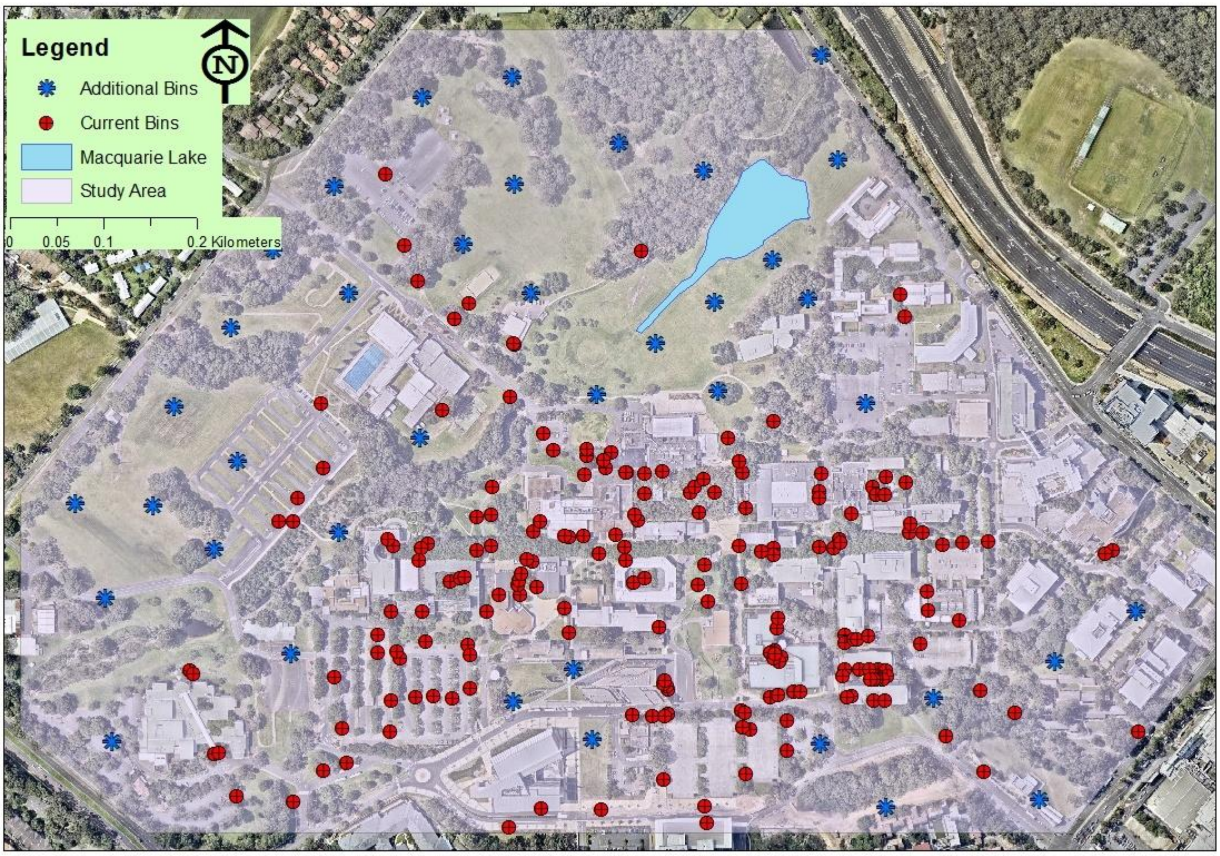
Appendix 4.2: Allocation of 20% of additional bins (39) to current distribution of 194 litter bins using 'maximize coverage' problem type but not considering population density at 52 meter impedance cut-off



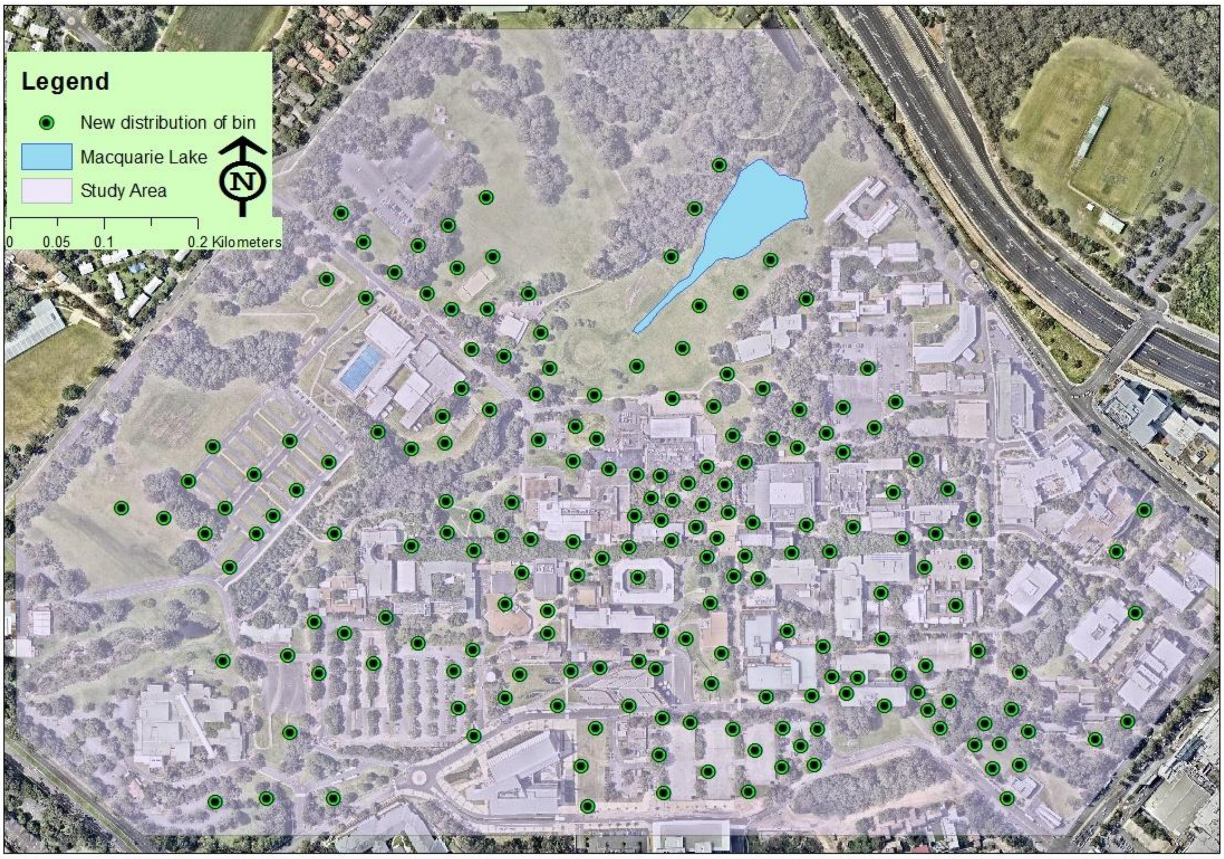
Appendix 4.3: Allocation of 20% of additional bins (39) to current distribution of 194 litter bins using 'maximize coverage' problem type but not considering population density at 63 meter impedance cut-off



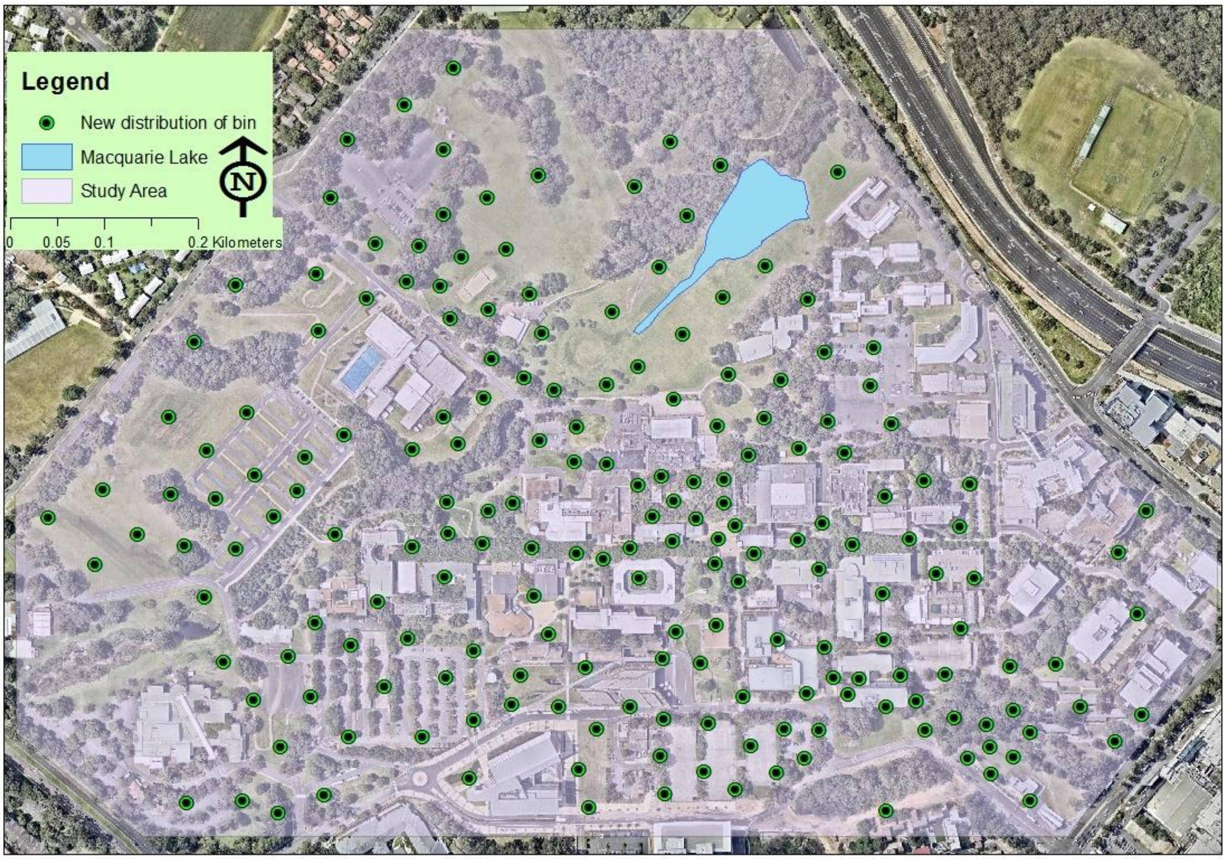
Appendix 4.4: Allocation of 20% of additional bins (39) to current distribution of 194 litter bins using 'maximize coverage' problem type but not considering population density at 80 meter impedance cut-off



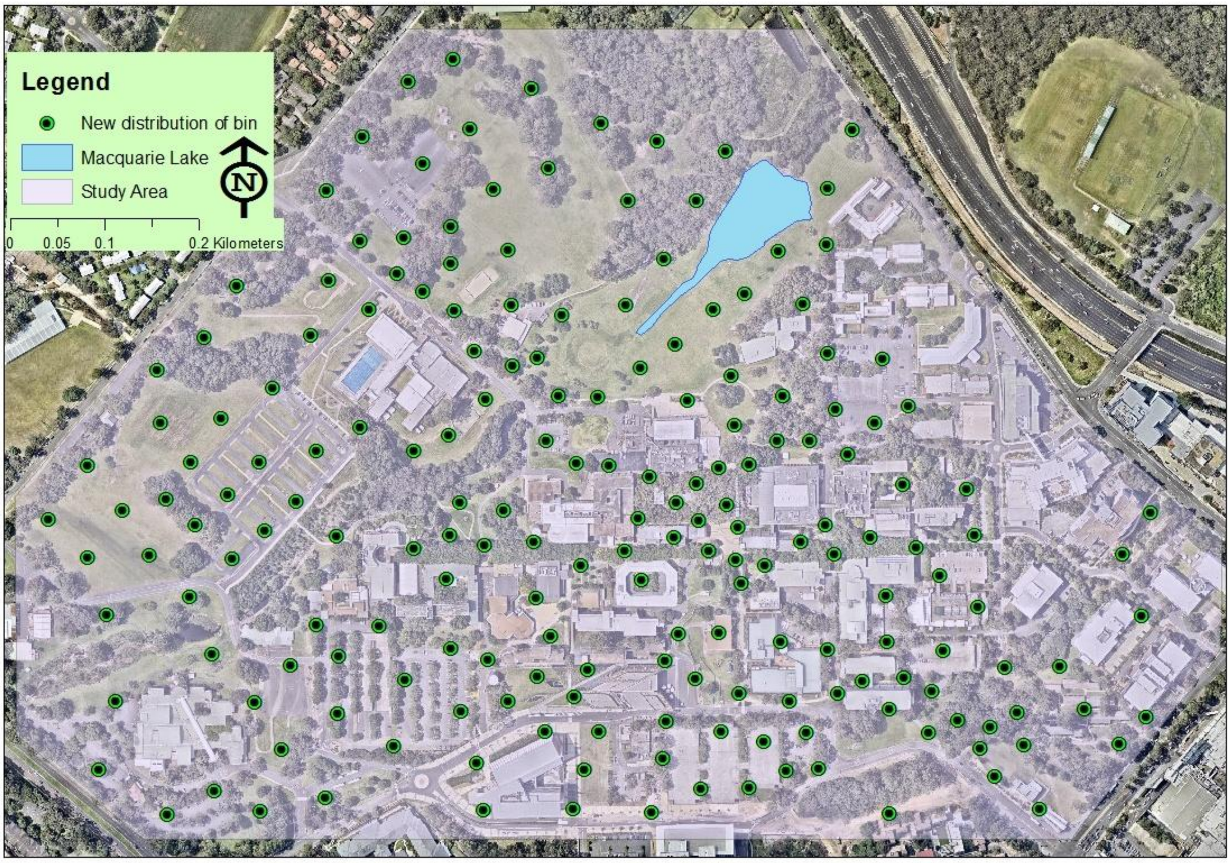
Appendix 4.5: Allocation of 20% of additional bins (39) to current distribution of 194 litter bins using 'maximize coverage' problem type but not considering population density at 400 meter impedance cut-off



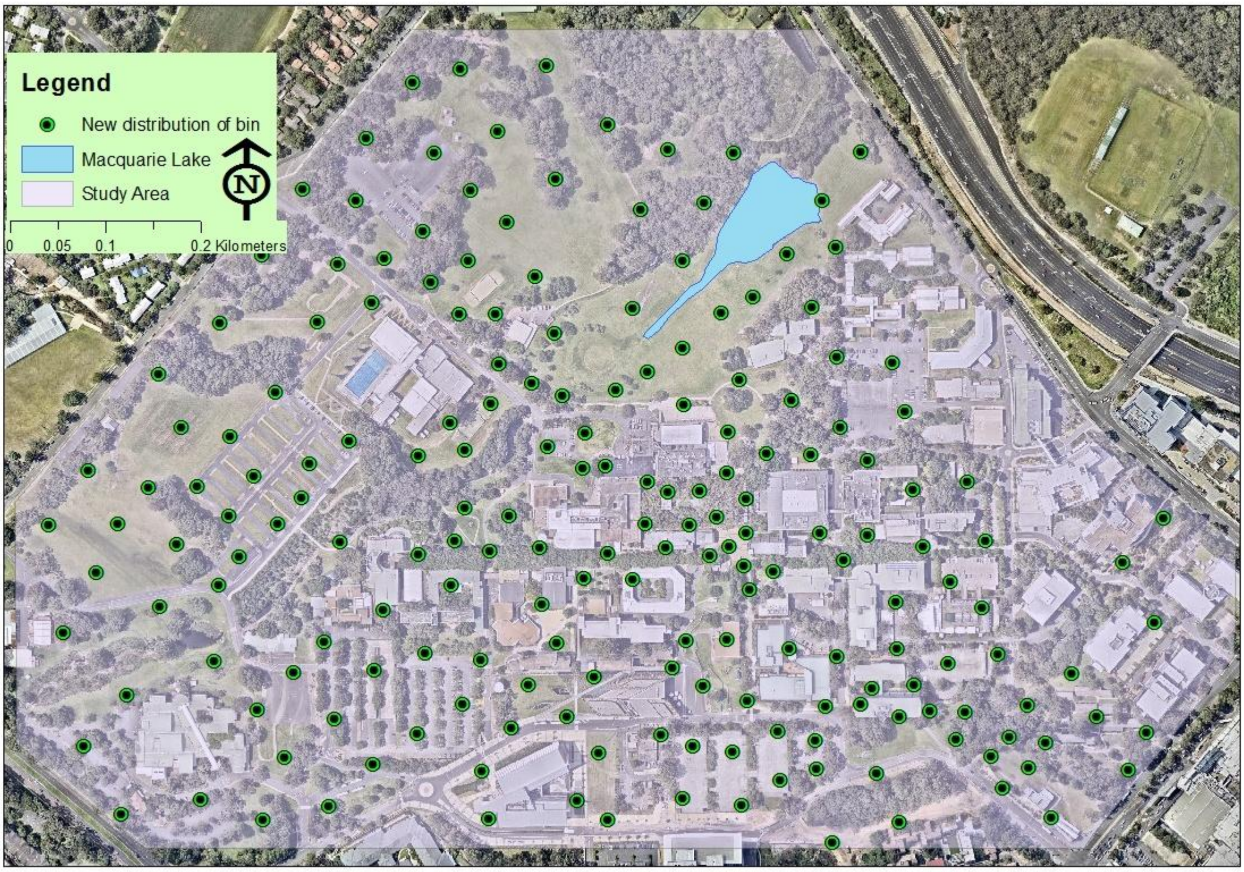
Appendix 5.1: Distribution of 194 litter bins using 'maximize attendance' problem type, considering population density and not considering current location of bins at 38 meter impedance cut-off



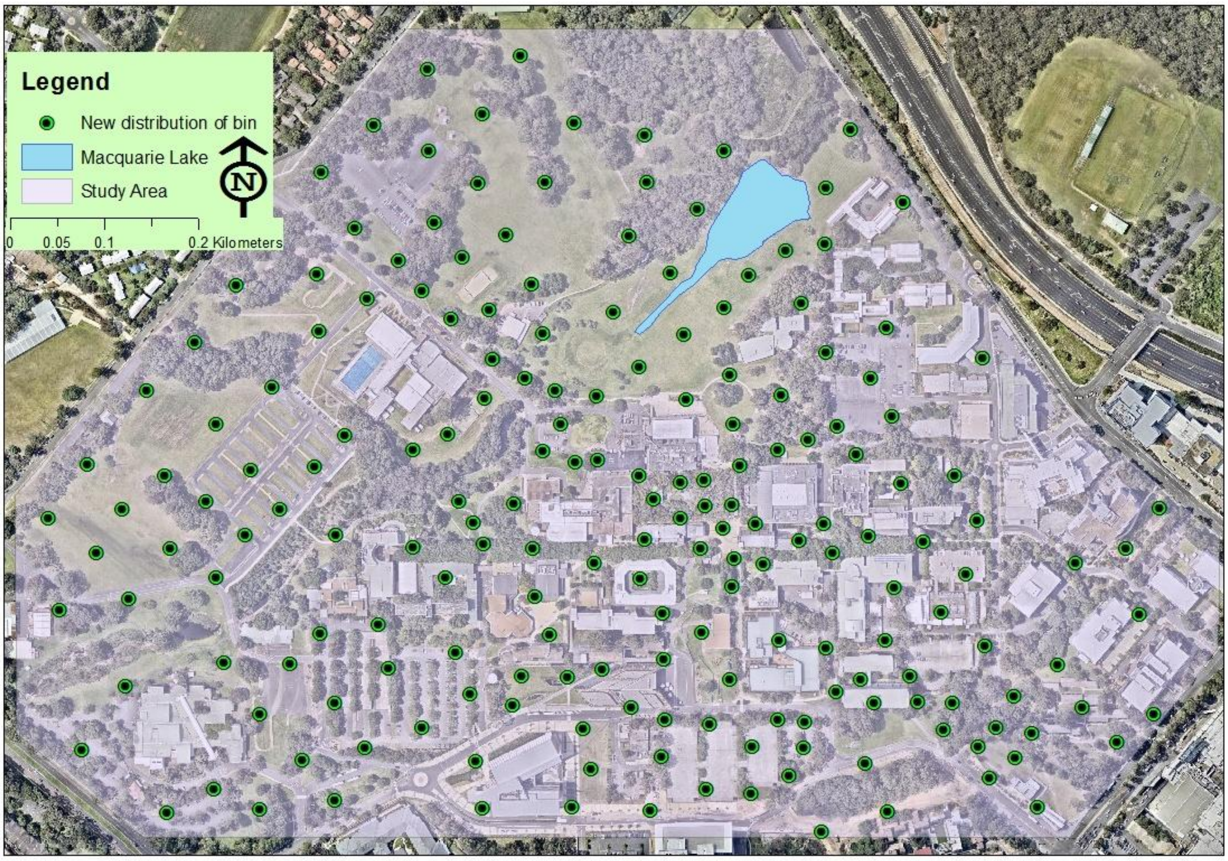
Appendix 5.2: Distribution of 194 litter bins using 'maximize attendance' problem type, considering population density and not considering current location of bins at 52 meter impedance cut-off



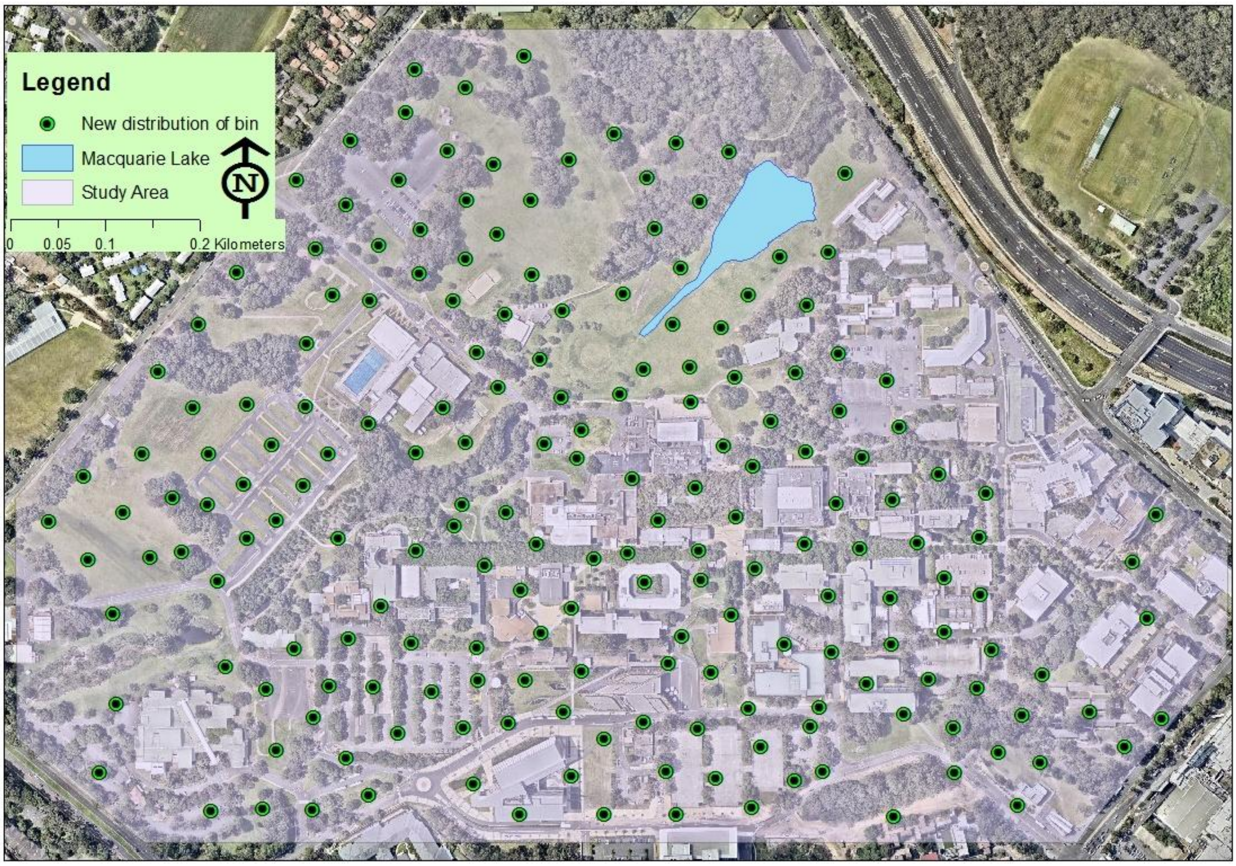
Appendix 5.3: Distribution of 194 litter bins using ‘maximize attendance’ problem type, considering population density and not considering current location of bins at 63 meter impedance cut-off



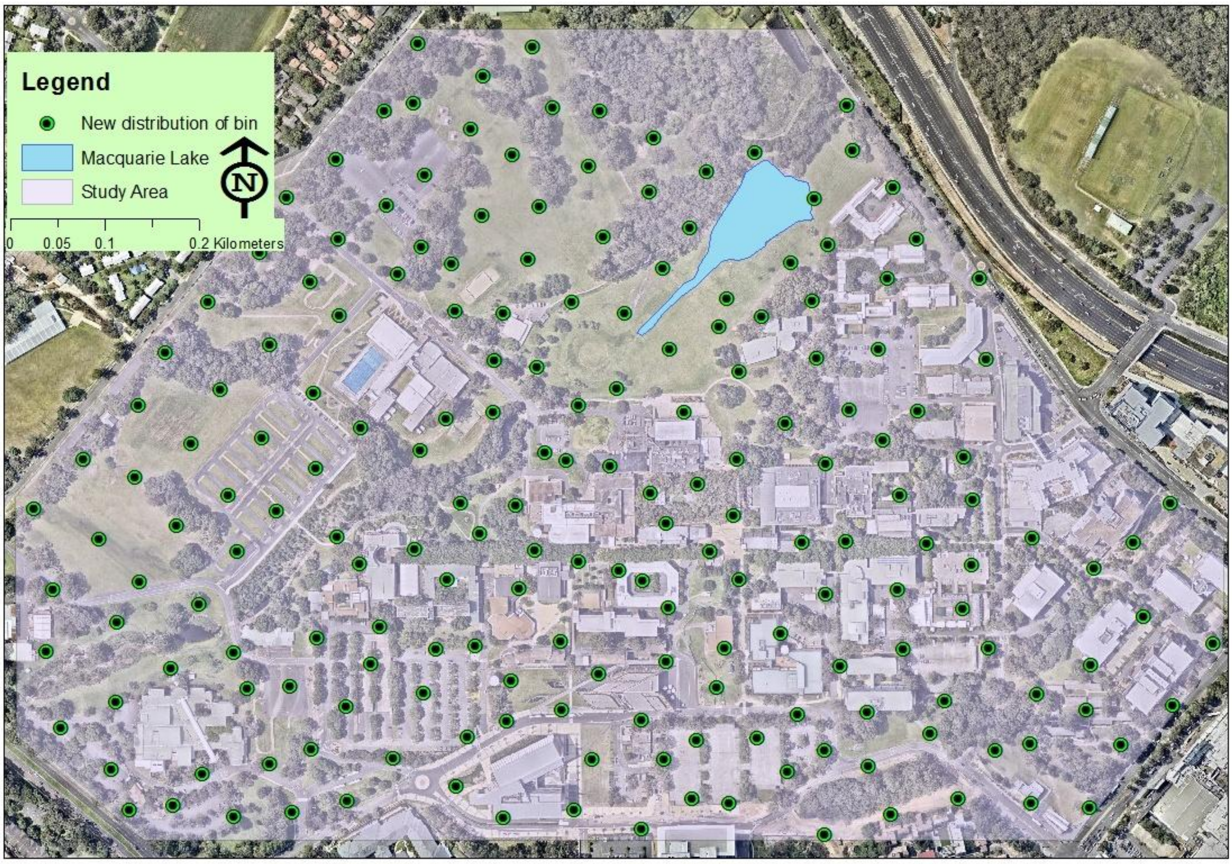
Appendix 5.4: Distribution of 194 litter bins using ‘maximize attendance’ problem type, considering population density and not considering current location of bins at 80 meter impedance cut-off



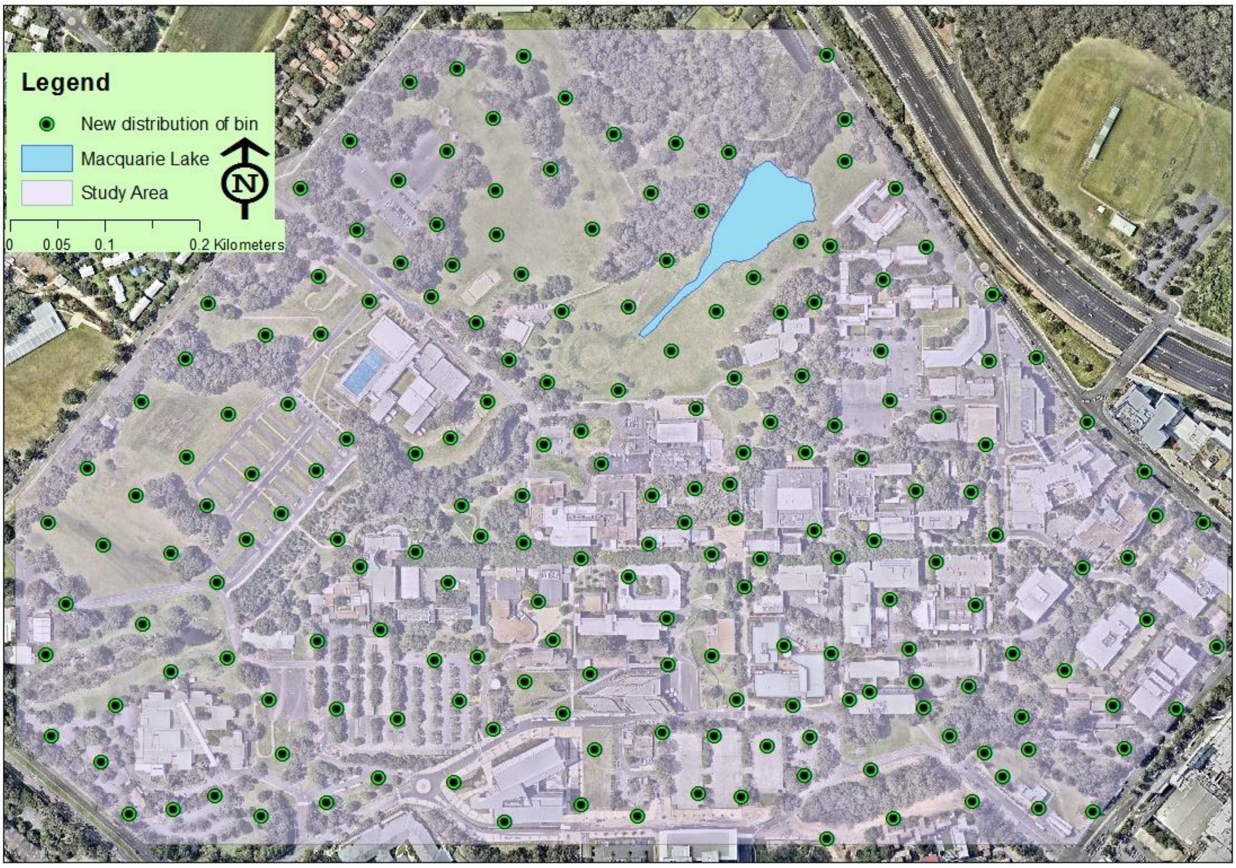
Appendix 5.5: Distribution of 194 litter bins using 'maximize attendance' problem type, considering population density and not considering current location of bins at 400 meter impedance cut-off



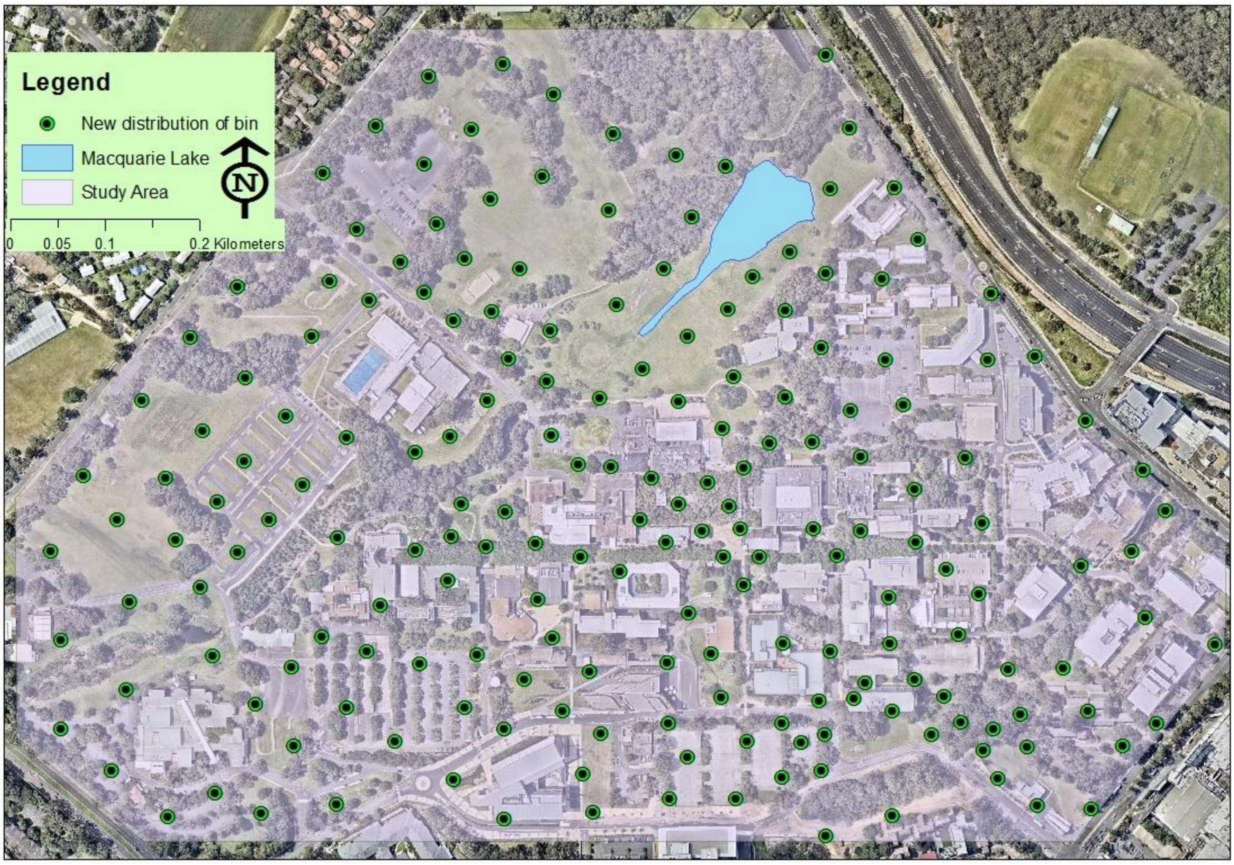
Appendix 6.1: Distribution of 194 litter bins using 'maximize coverage' problem type without considering population density and current location of bins at 38 meter impedance cut-off



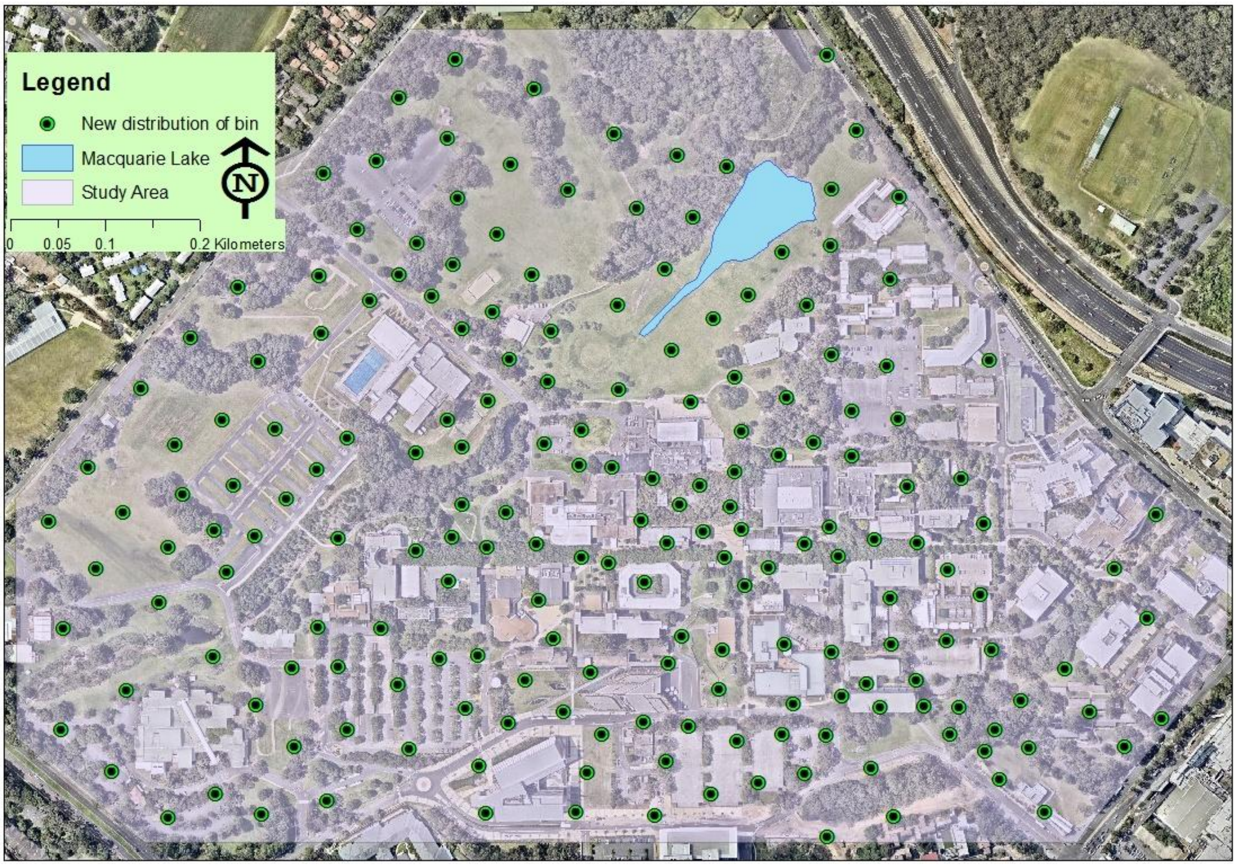
Appendix 6.2: Distribution of 194 litter bins using ‘maximize coverage’ problem type without considering population density and current location of bins at 52 meter impedance cut-off



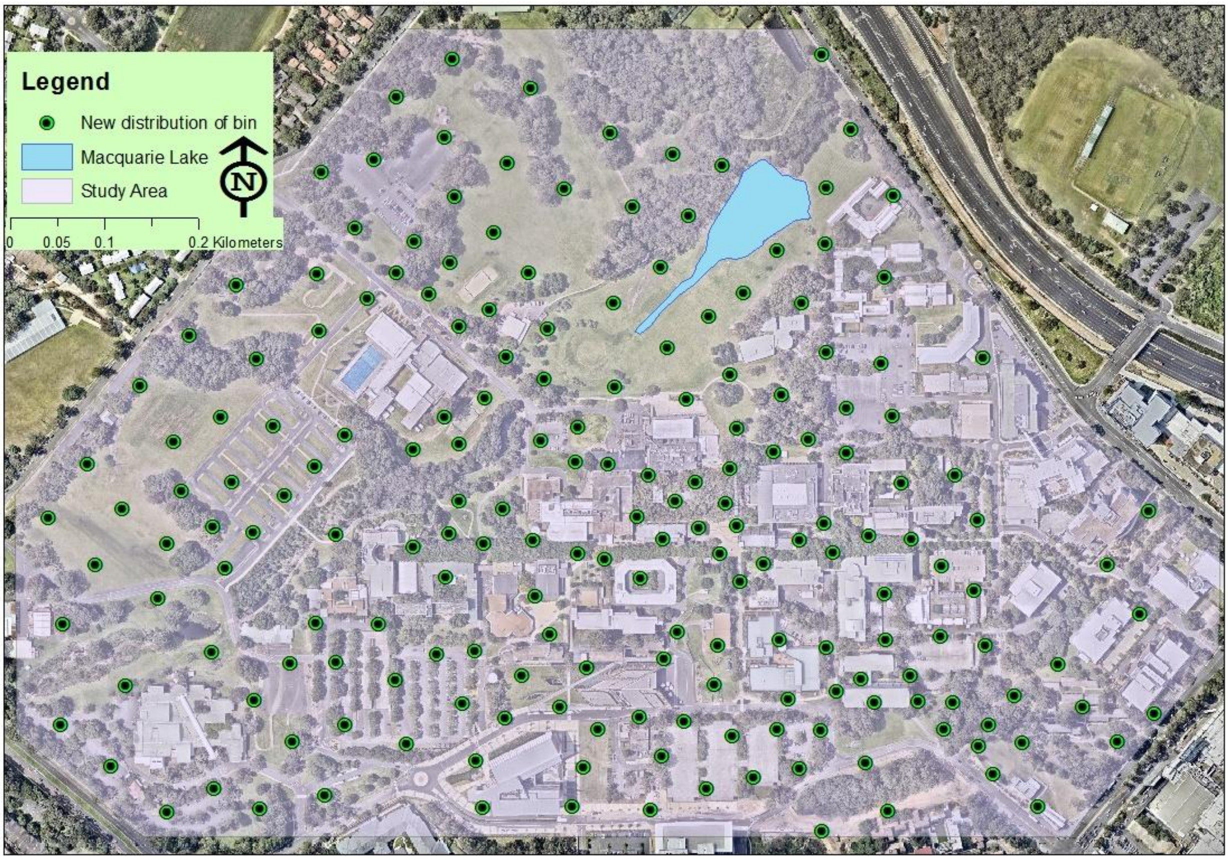
Appendix 6.3: Distribution of 194 litter bins using ‘maximize coverage’ problem type without considering population density and current location of bins at 63 meter impedance cut-off



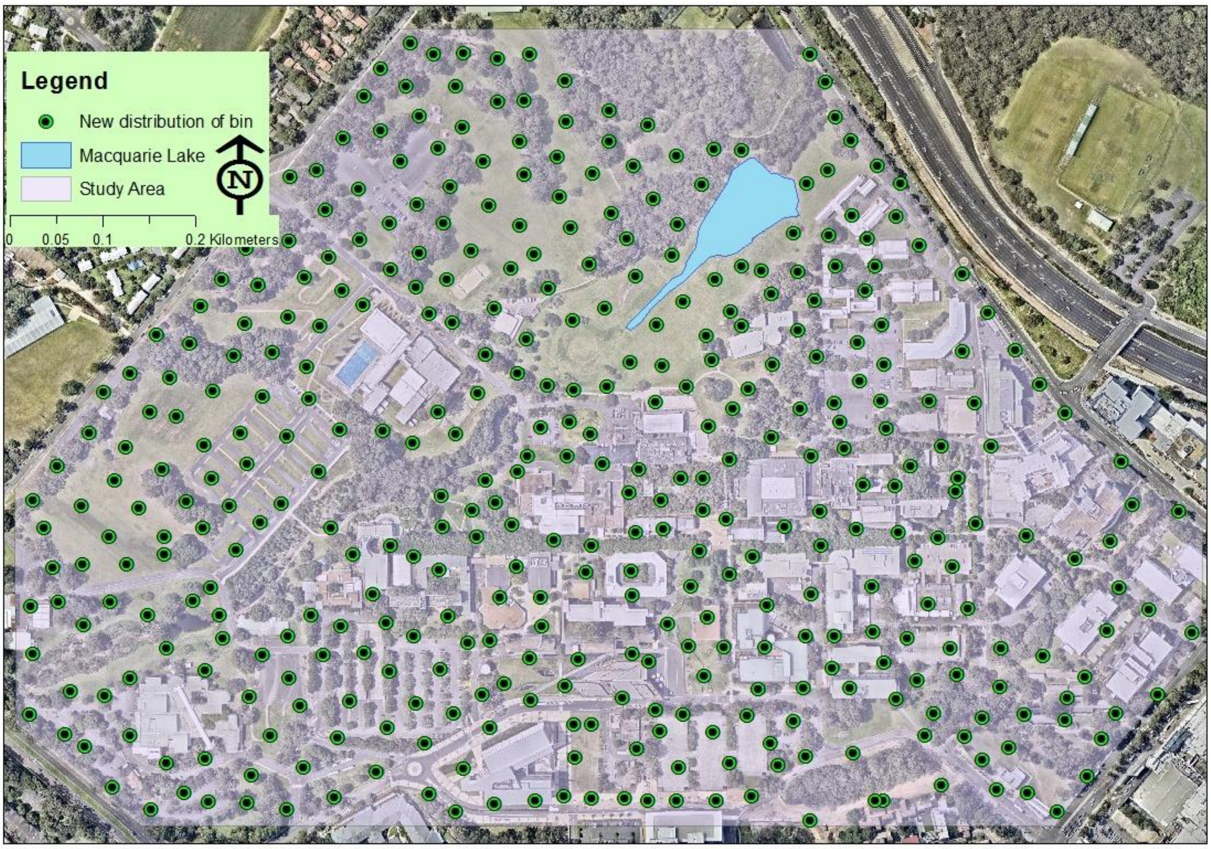
Appendix 6.4: Distribution of 194 litter bins using 'maximize coverage' problem type without considering population density and current location of bins at 80 meter impedance cut-off



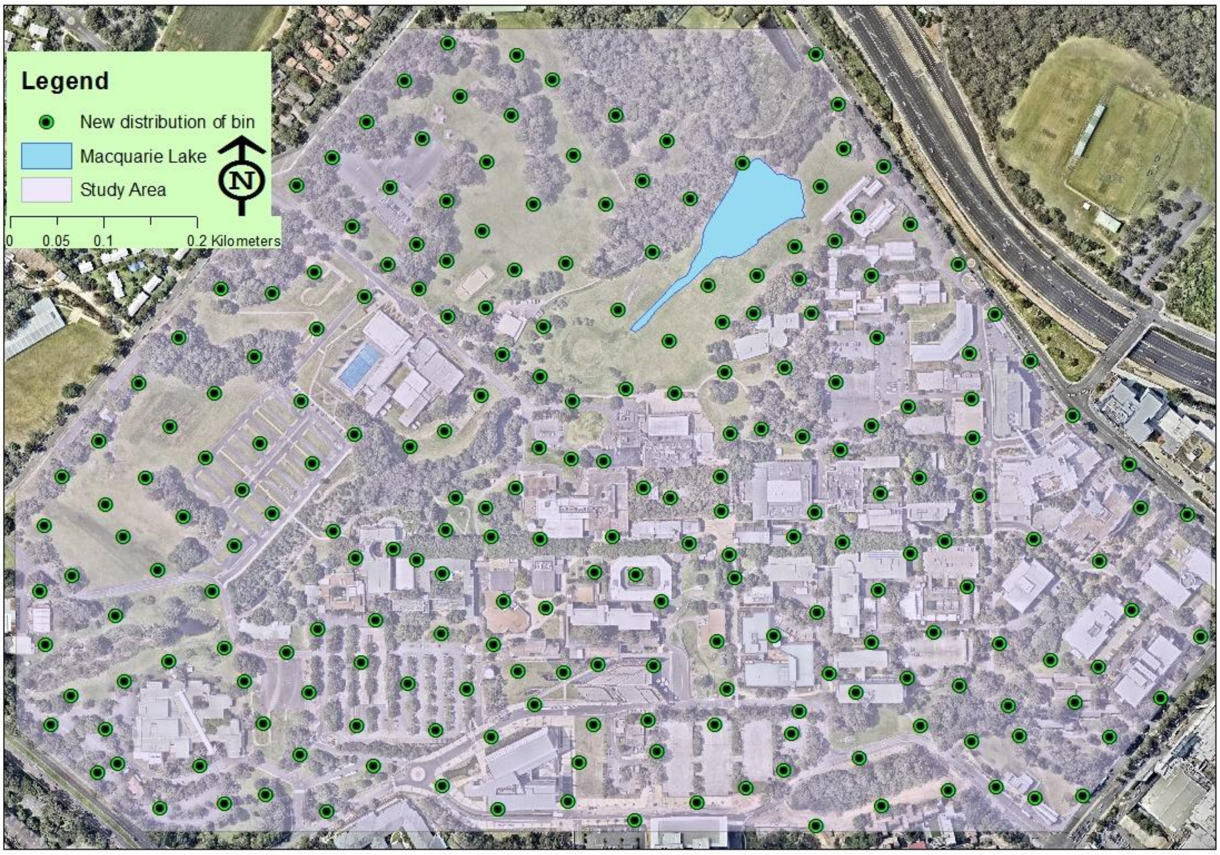
Appendix 6.5: Distribution of 194 litter bins using 'maximize coverage' problem type without considering population density and current location of bins at 400 meter impedance cut-off



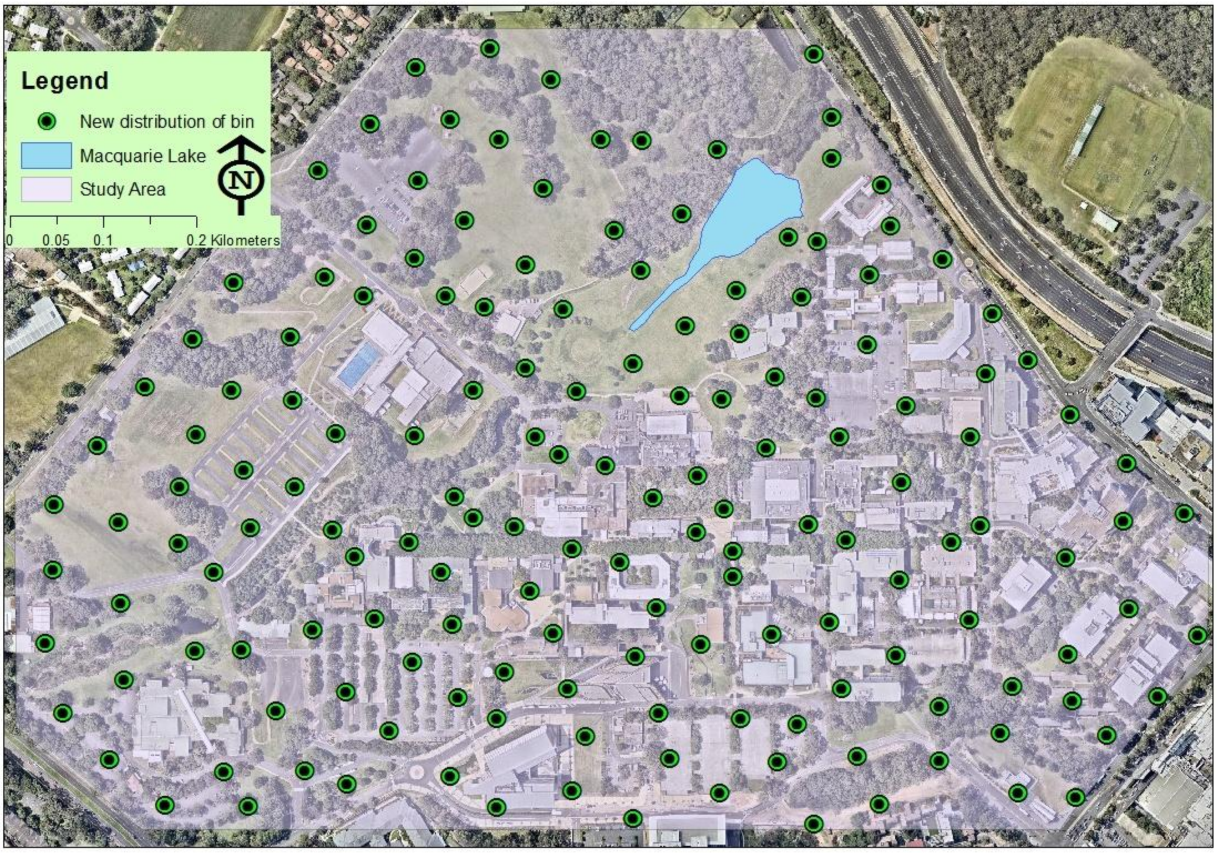
Appendix 7: Distribution of 194 litter bins using 'minimize impedance' problem type, not considering population density and current location of bins



Appendix 8.1: Distribution of litter bins using 'minimize facilities' problem type, not considering population density and current location of bins at 38 meter impedance cut-off
Number of bins allocated =398



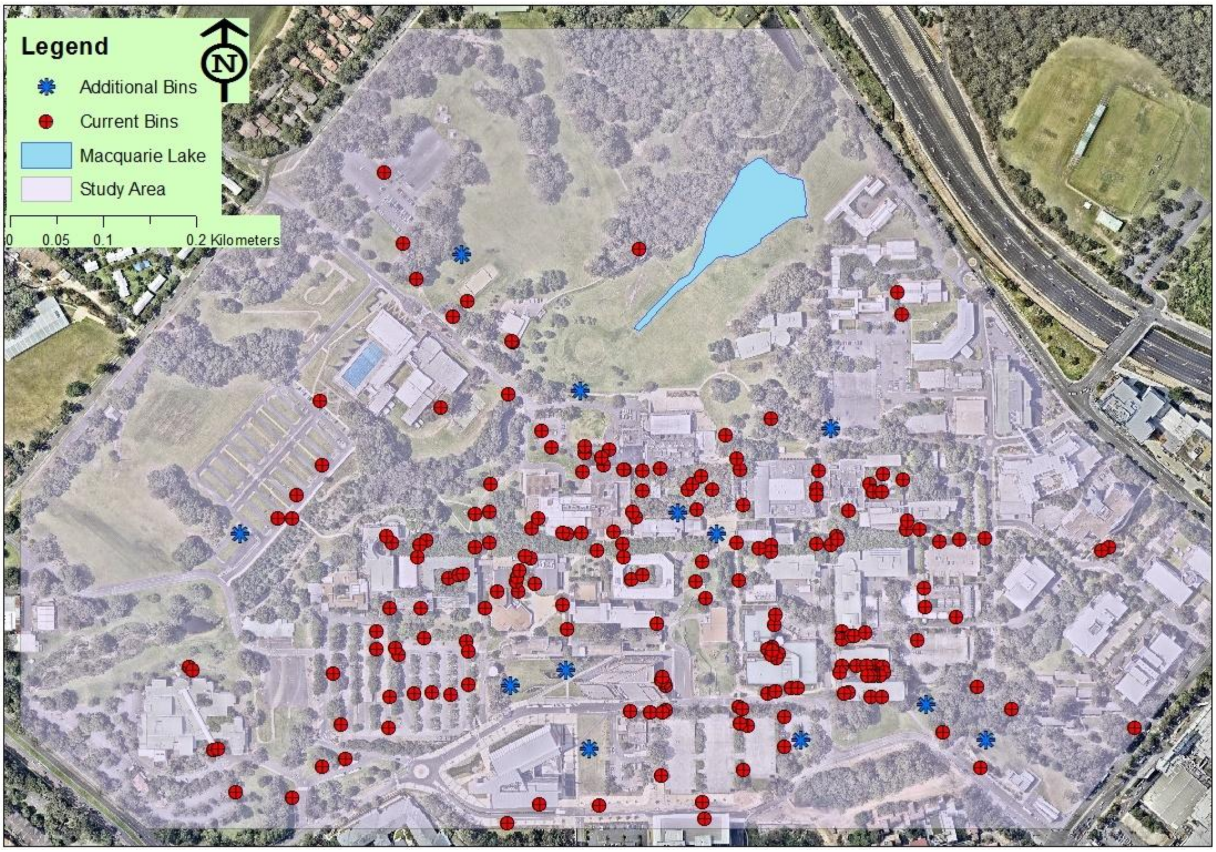
Appendix 8.2: Distribution of litter bins using 'minimize facilities' problem type, not considering population density and current location of bins at 52 meter impedance cut-off,
Number of bins allocated =227



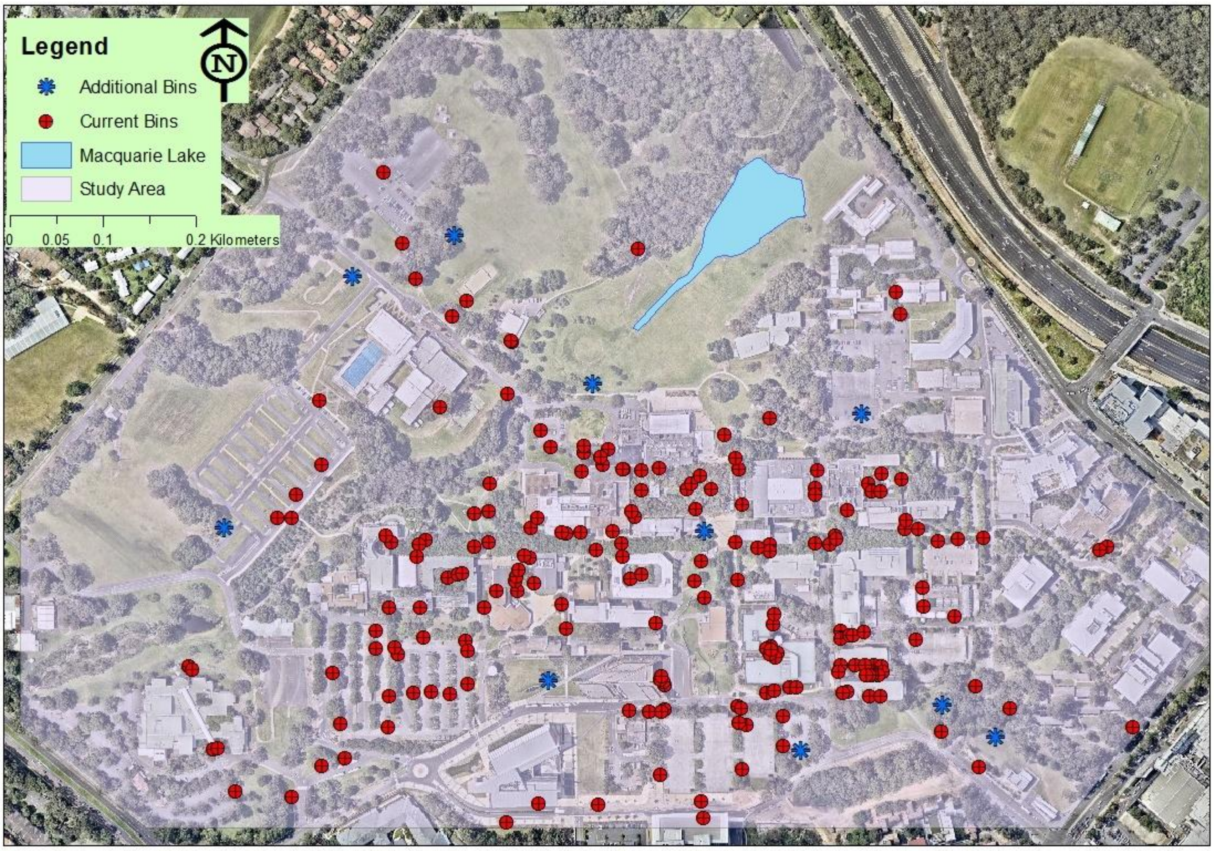
Appendix 8.3: Distribution of litter bins using 'minimize facilities' problem type, not considering population density and current location of bins at 63 meter impedance cut-off
Number of bins allocated =161

Appendix 8.4: Distribution of litter bins using 'minimize facilities' problem type, not considering population density and current location of bins at 80 meter impedance cut-off
Number of bins allocated =109

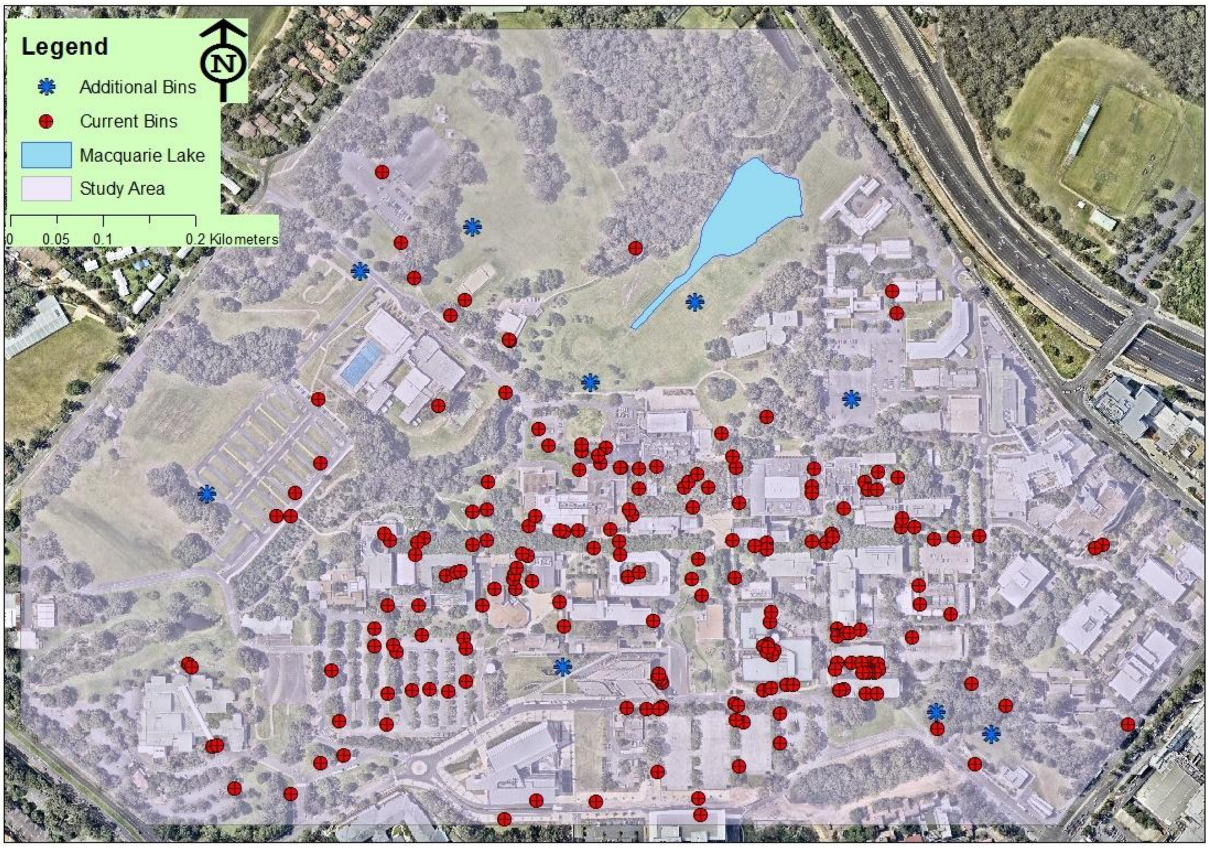
Appendix 8.5: Distribution of litter bins using 'minimize facilities' problem type, not considering population density and current location of bins at 400 meter impedance cut-off,
Number of bins allocated =11



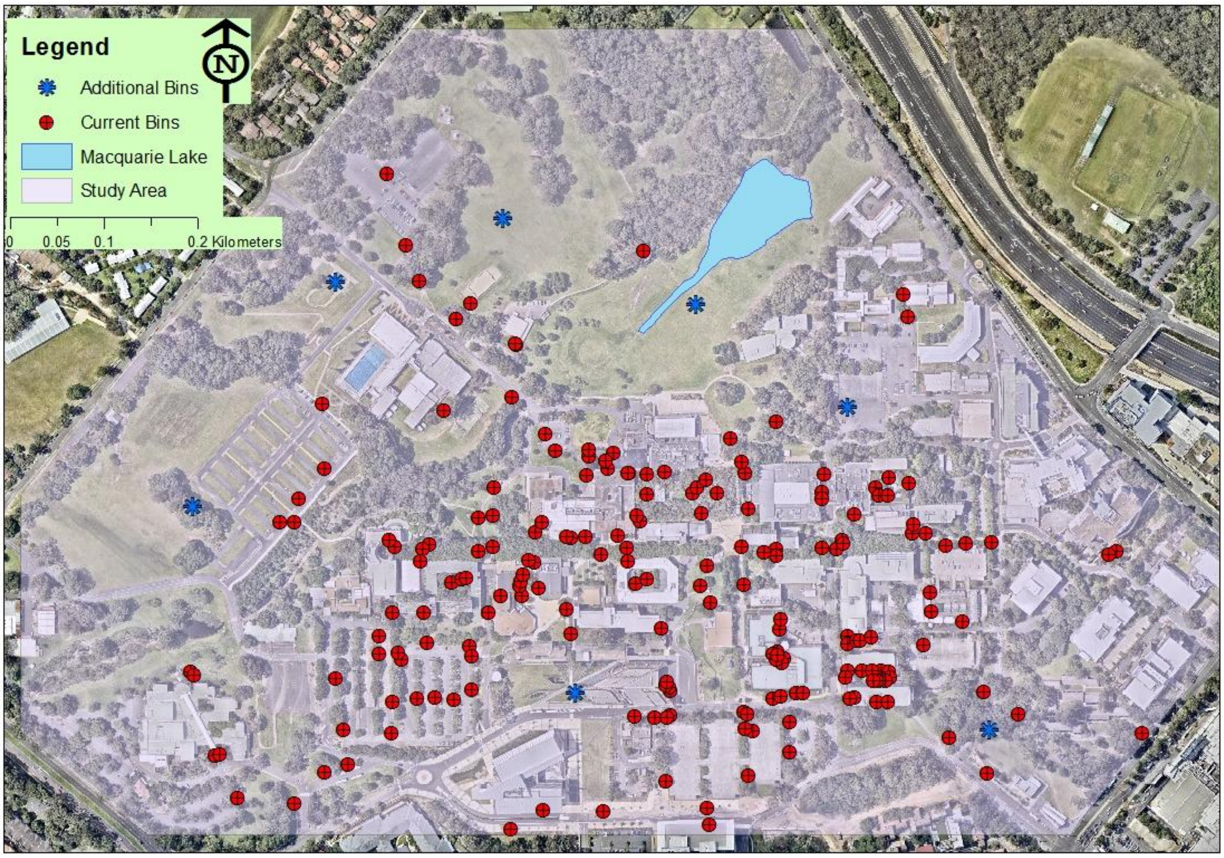
Appendix 9.1: Distribution of litter bins using 'target market share' problem type at 10% market share, considering population density and current location of bins at 38 meter impedance cut-off
Number of additional bins allocated =12



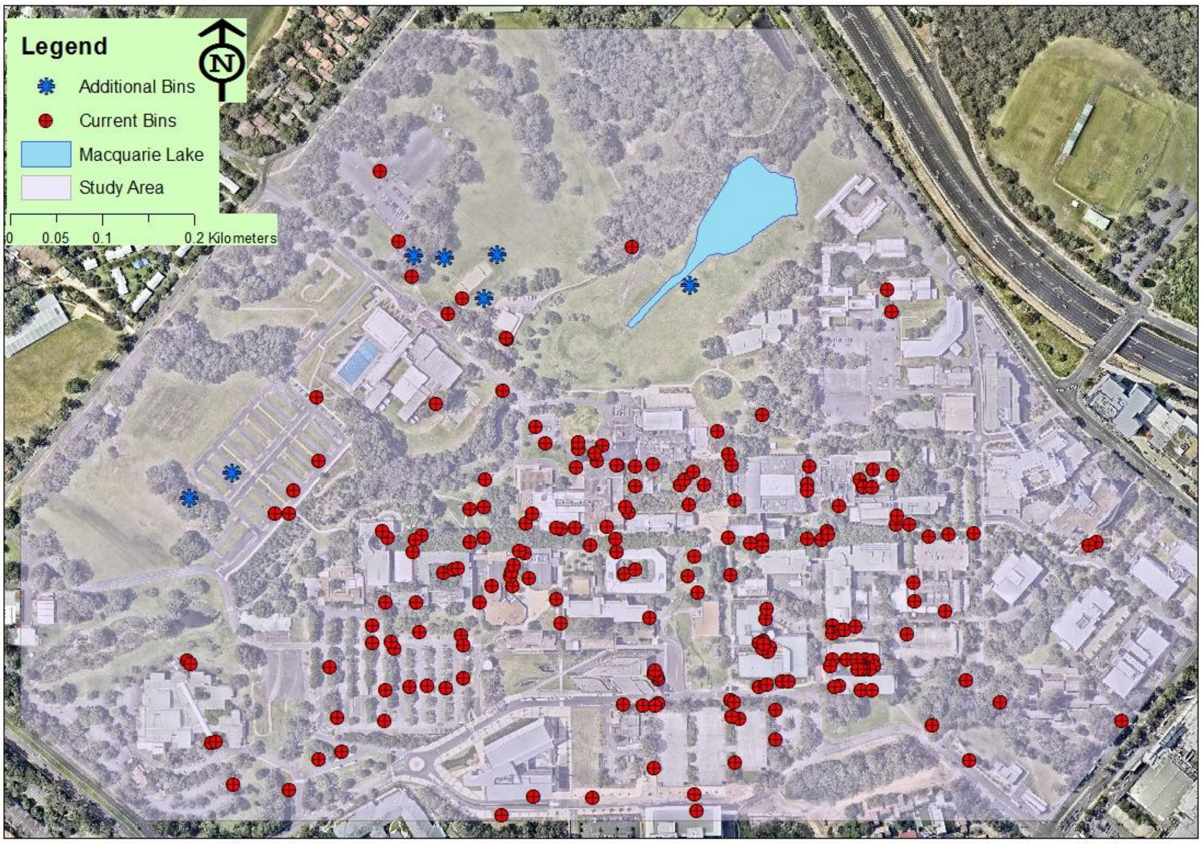
Appendix 9.2: Distribution of litter bins using 'target market share' problem type at 10% market share, considering population density and current location of bins at 52 meter impedance cut-off
Number of additional bins allocated =10



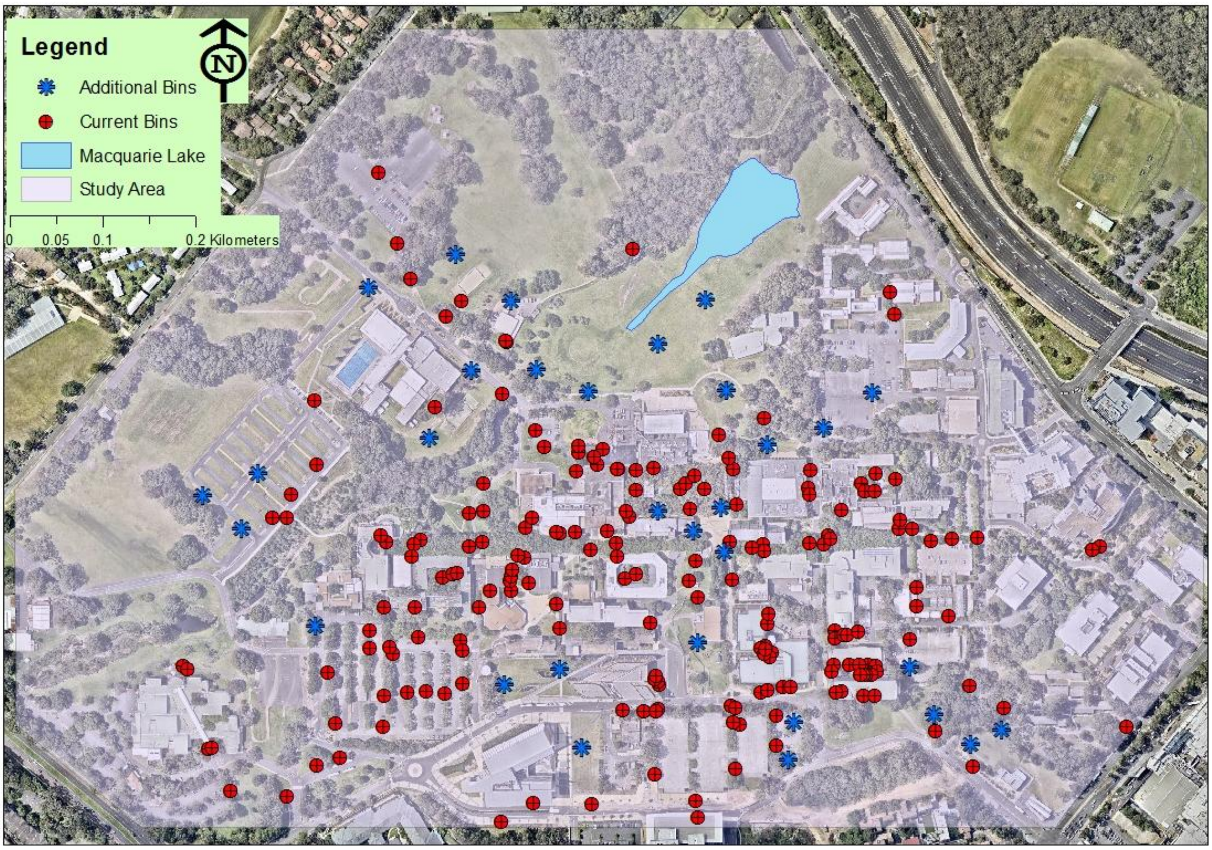
Appendix 9.3: Distribution of litter bins using ‘target market share’ problem type at 10% market share, considering population density and current location of bins at 63 meter impedance cut-off
Number of additional bins allocated =9



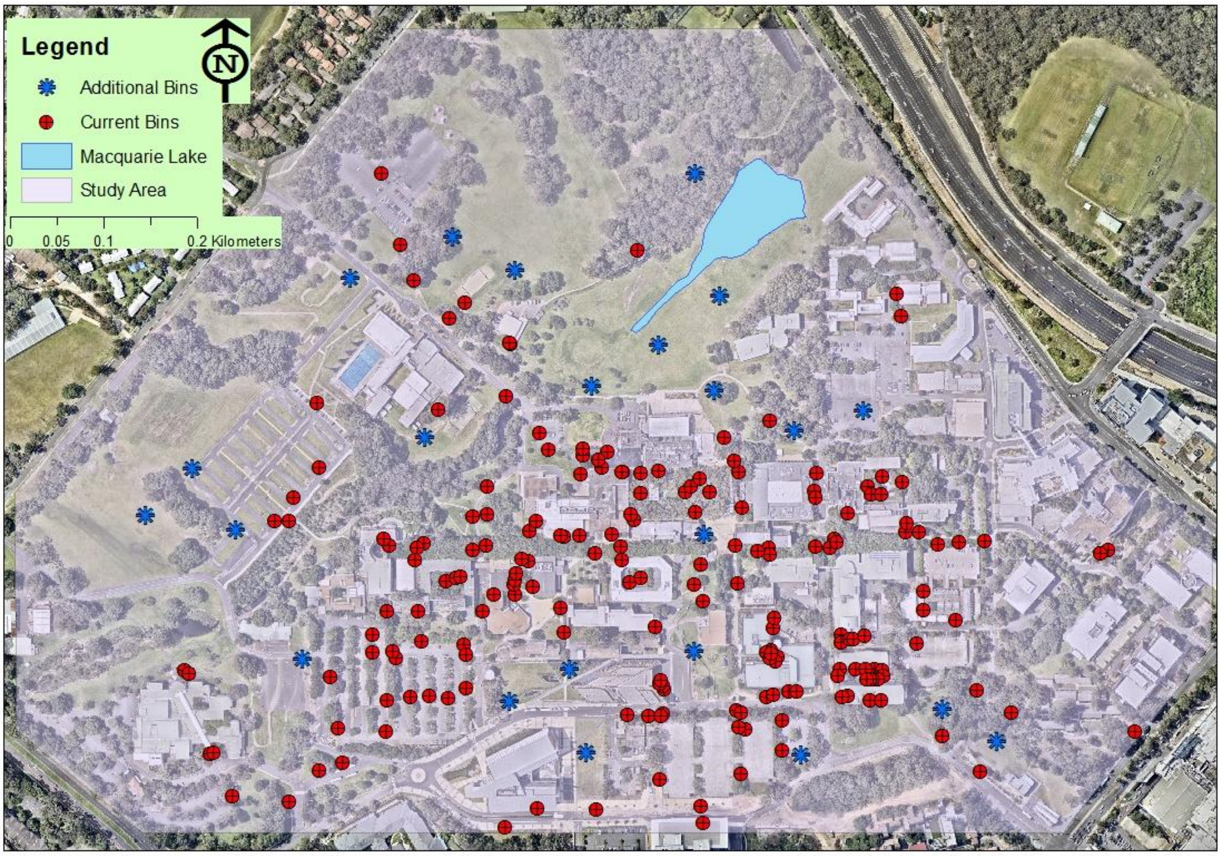
Appendix 9.4: Distribution of litter bins using ‘target market share’ problem type at 10% market share, considering population density and current location of bins at 80 meter impedance cut-off
Number of additional bins allocated =7



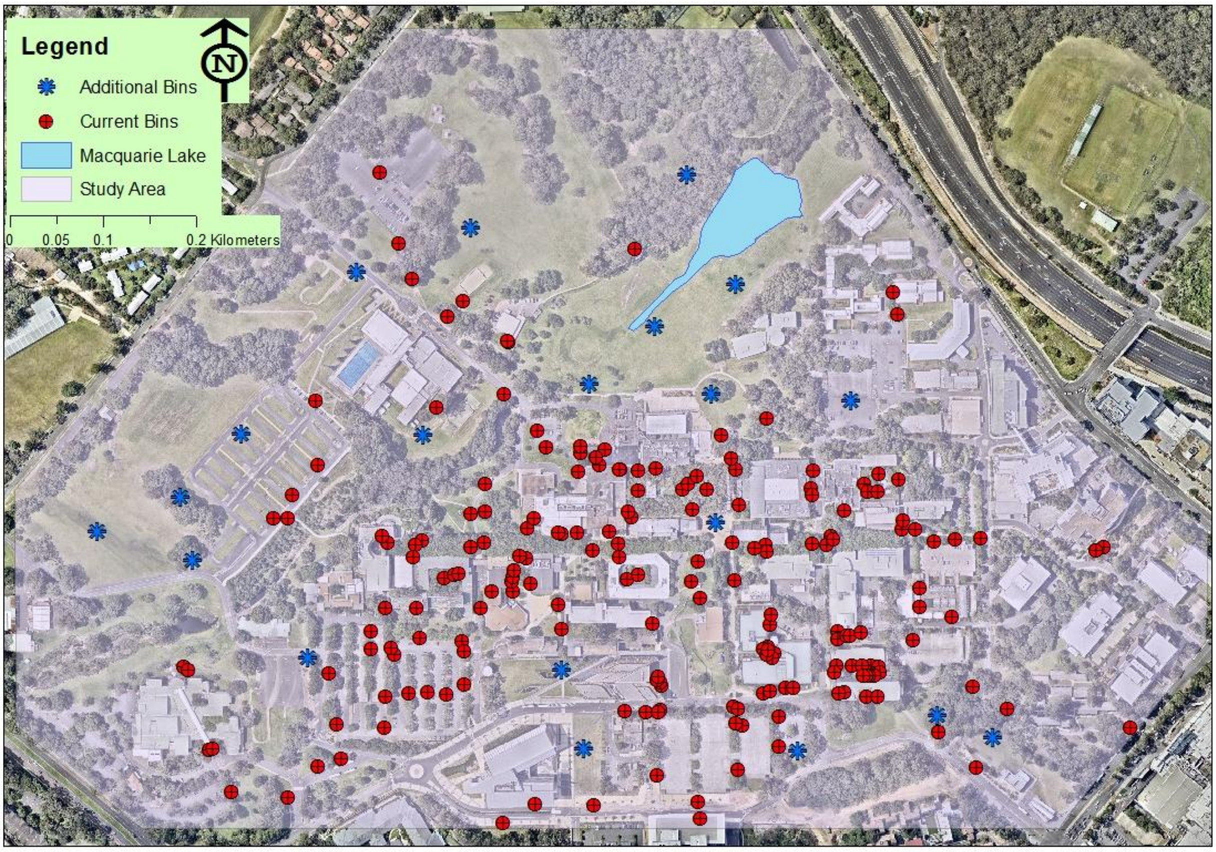
Appendix 9.5: Distribution of litter bins using 'target market share' problem type at 10% market share, considering population density and current location of bins at 400 meter impedance cut-off
Number of additional bins allocated =7



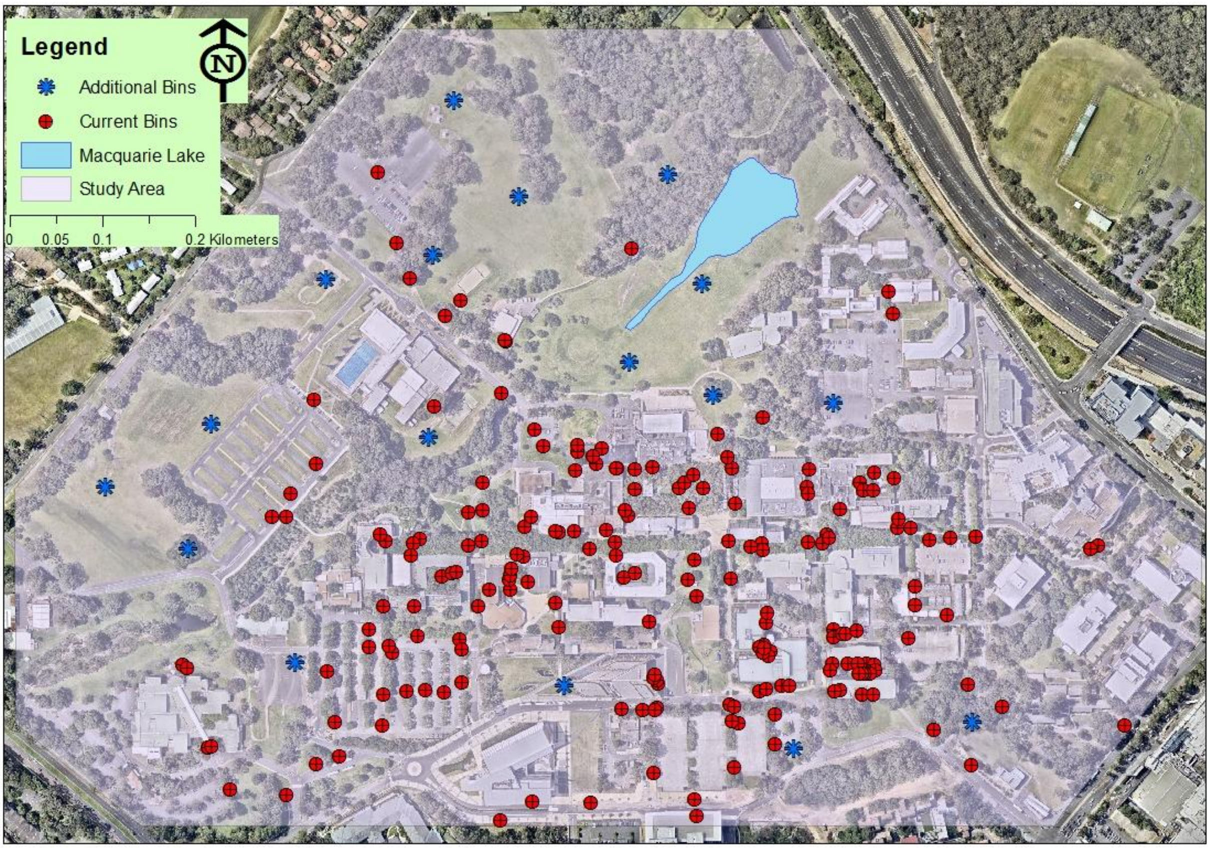
Appendix 10.1: Distribution of litter bins using 'target market share' problem type at 20% market share, considering population density and current location of bins at 38 meter impedance cut-off
Number of additional bins allocated =31



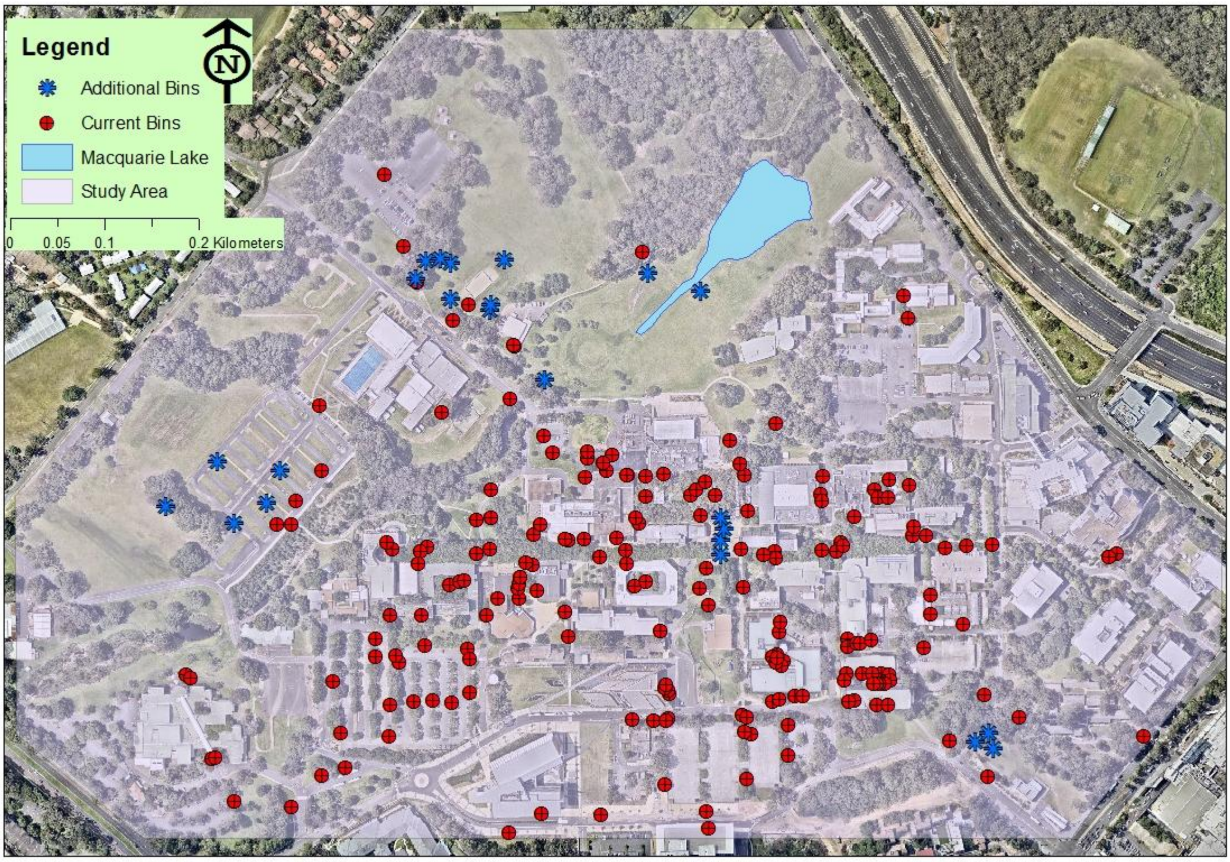
Appendix 10.2: Distribution of litter bins using ‘target market share’ problem type at 20% market share, considering population density and current location of bins at 52 meter impedance cut-off
Number of additional bins allocated =23



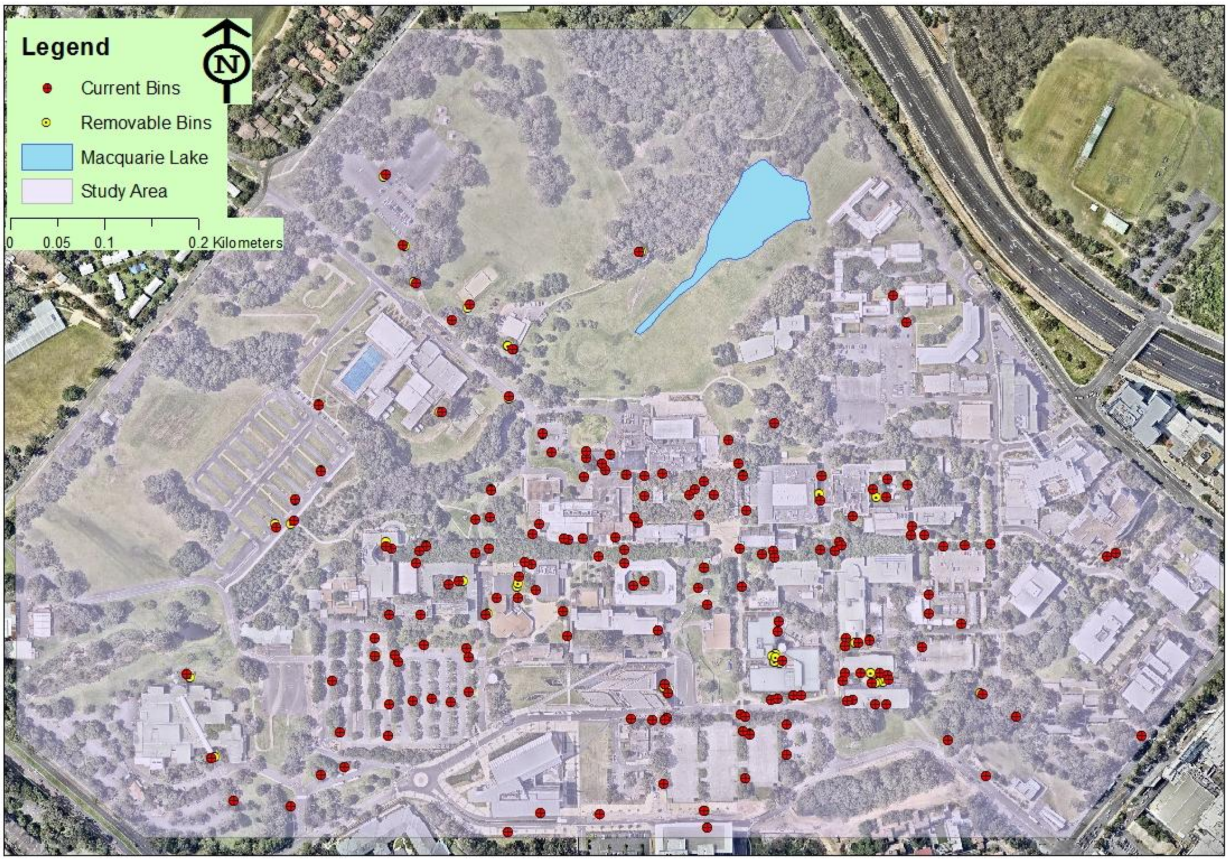
Appendix 10.3: Distribution of litter bins using ‘target market share’ problem type at 20% market share, considering population density and current location of bins at 63 meter impedance cut-off
Number of additional bins allocated =20



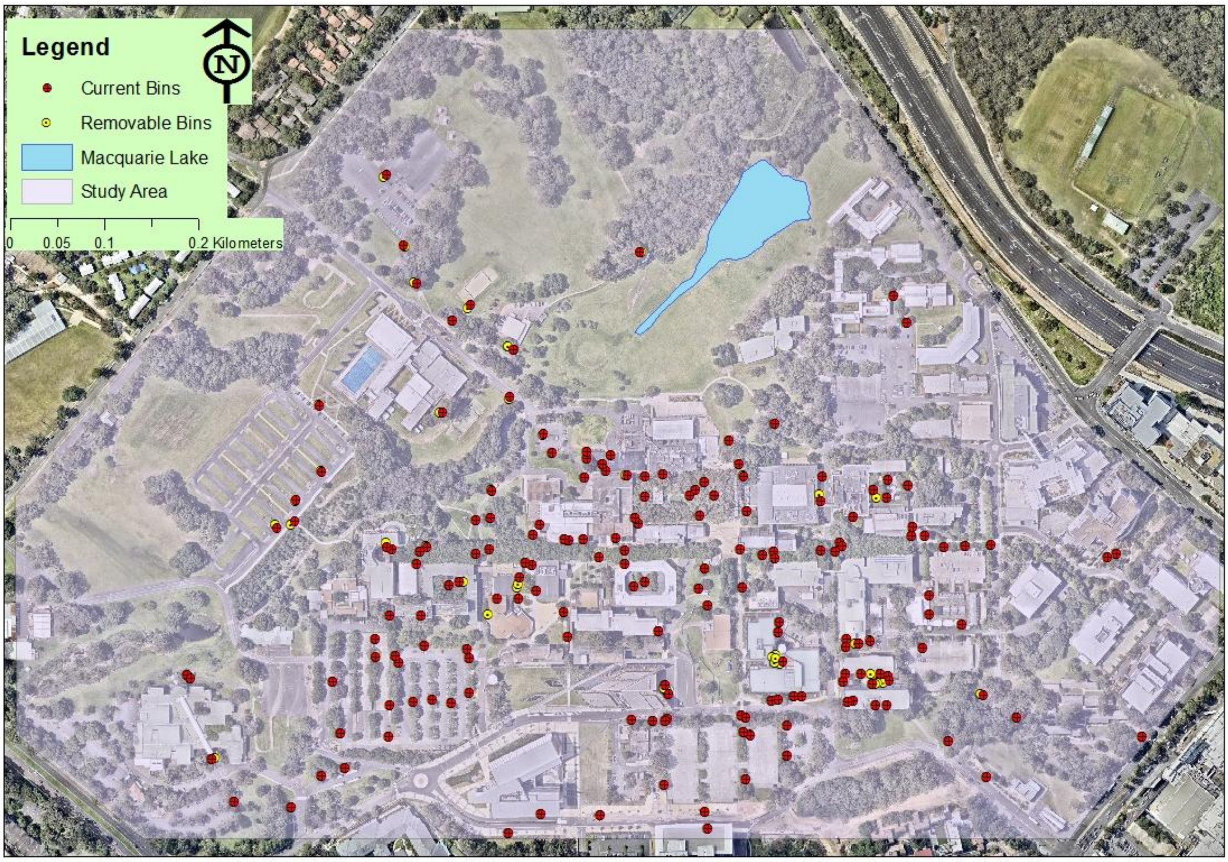
Appendix 10.4: Distribution of litter bins using 'target market share' problem type at 20% market share, considering population density and current location of bins at 80 meter impedance cut-off
Number of additional bins allocated =17



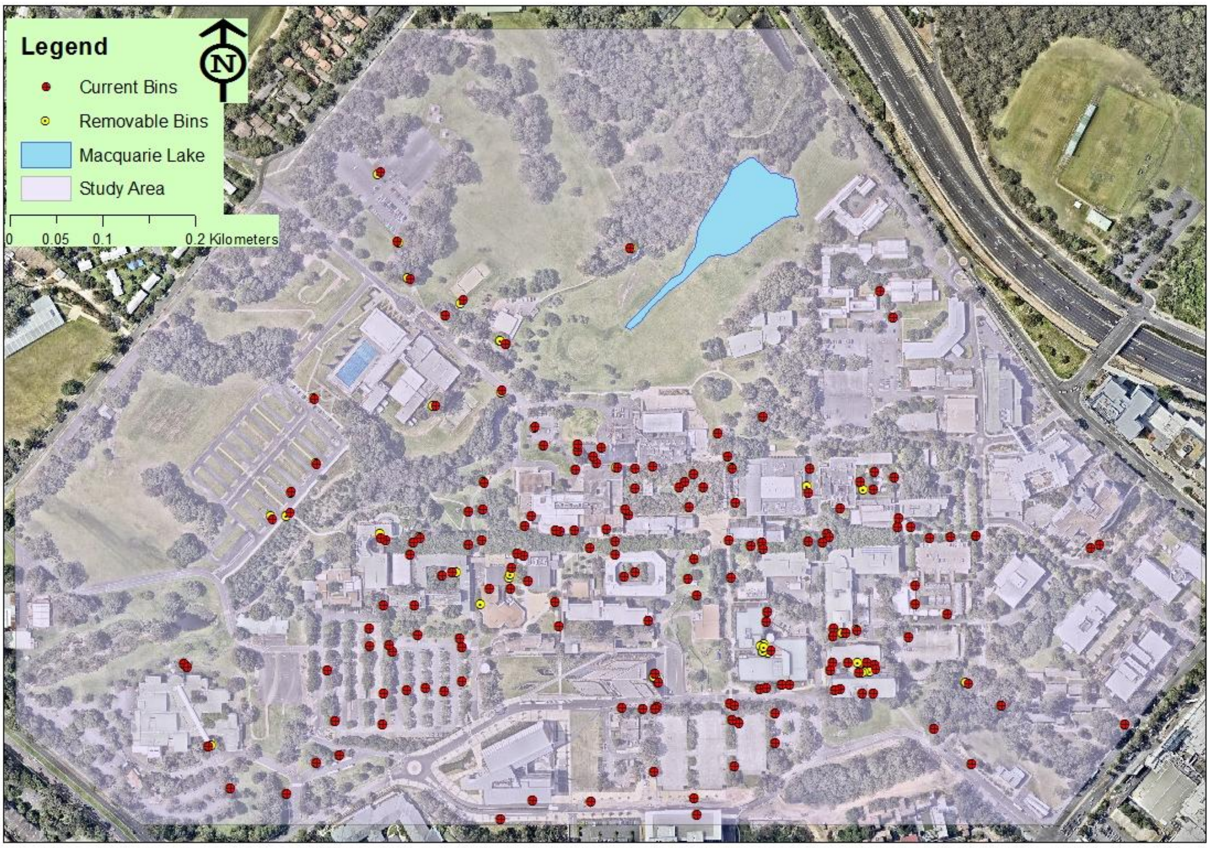
Appendix 10.5: Distribution of litter bins using 'target market share' problem type at 20% market share, considering population density and current location of bins at 400 meter impedance cut-off
Number of additional bins allocated =23



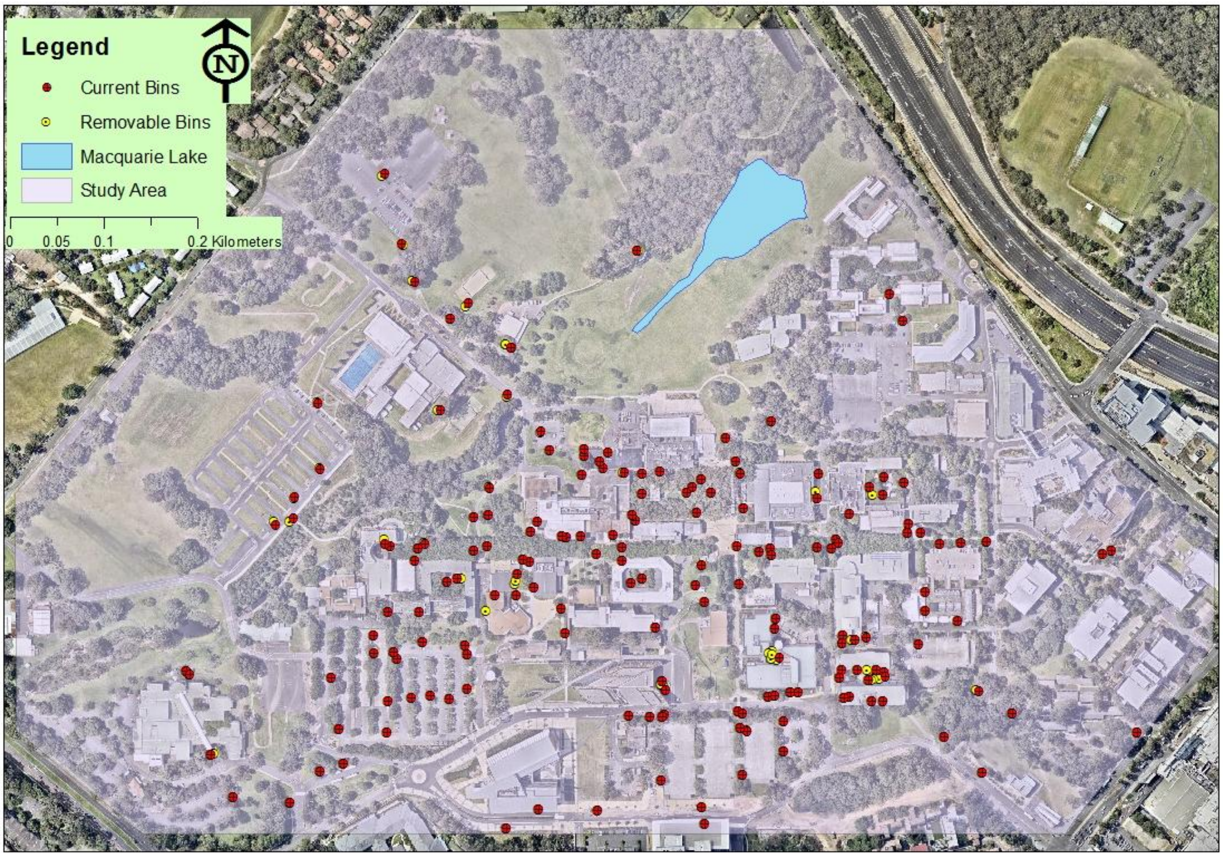
Appendix 11.1: Reducing 10% of bins (20) from current distribution of 194 litter bins using 'maximize attendance' problem type and considering population density at 38 meter impedance cut-off



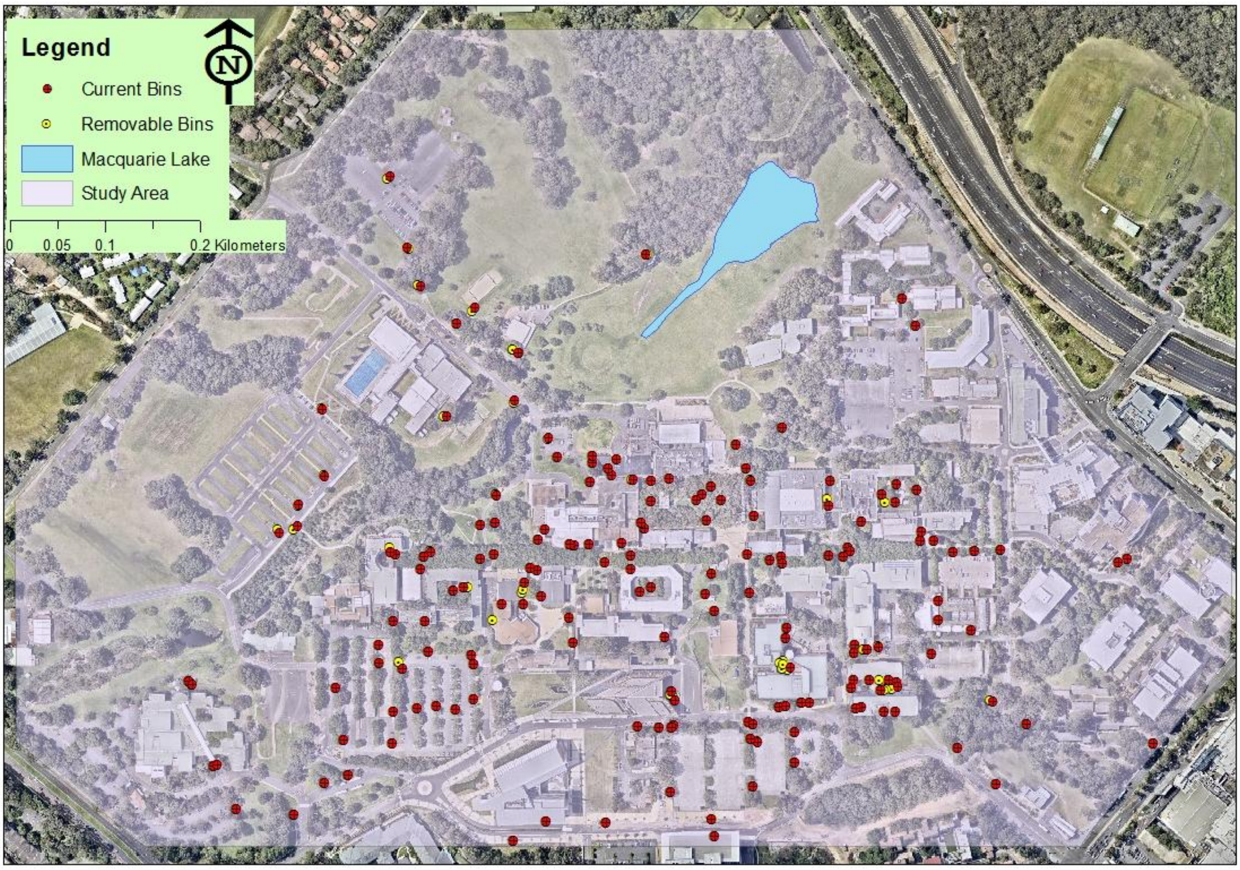
Appendix 11.2: Reducing 10% of bins (20) from current distribution of 194 litter bins using 'maximize attendance' problem type and considering population density at 52 meter impedance cut-off



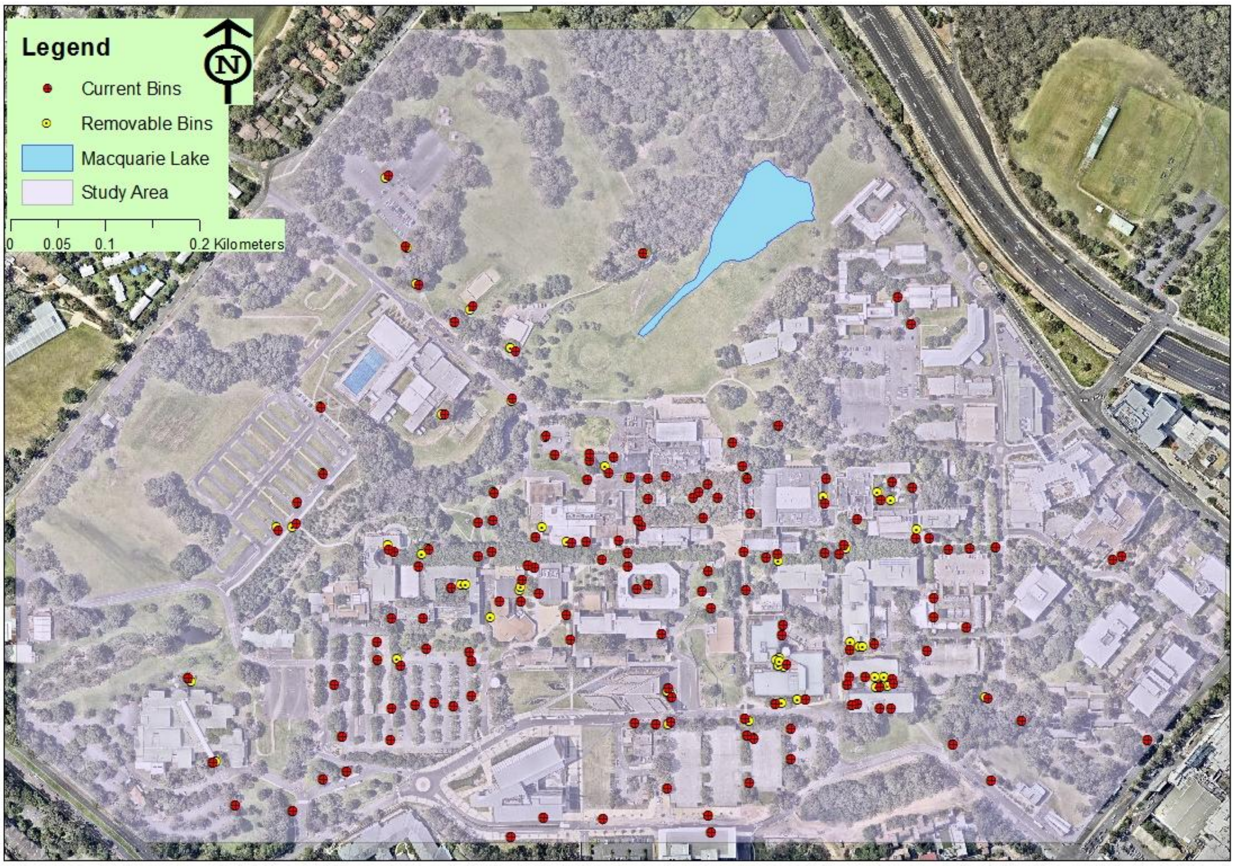
Appendix 11.3: Reducing 10% of bins (20) from current distribution of 194 litter bins using 'maximize attendance' problem type and considering population density at 63 meter impedance cut-off



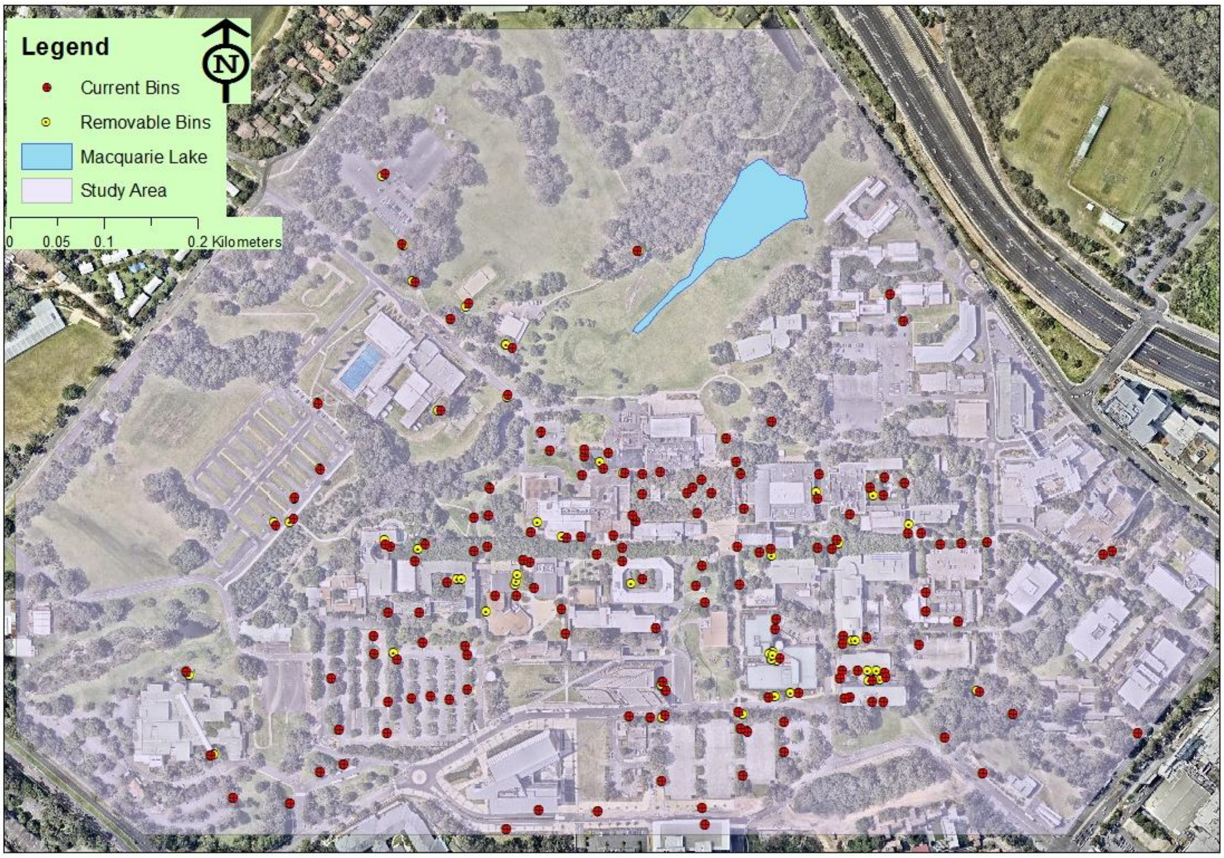
Appendix 11.4: Reducing 10% of bins (20) from current distribution of 194 litter bins using 'maximize attendance' problem type and considering population density at 80 meter impedance cut-off



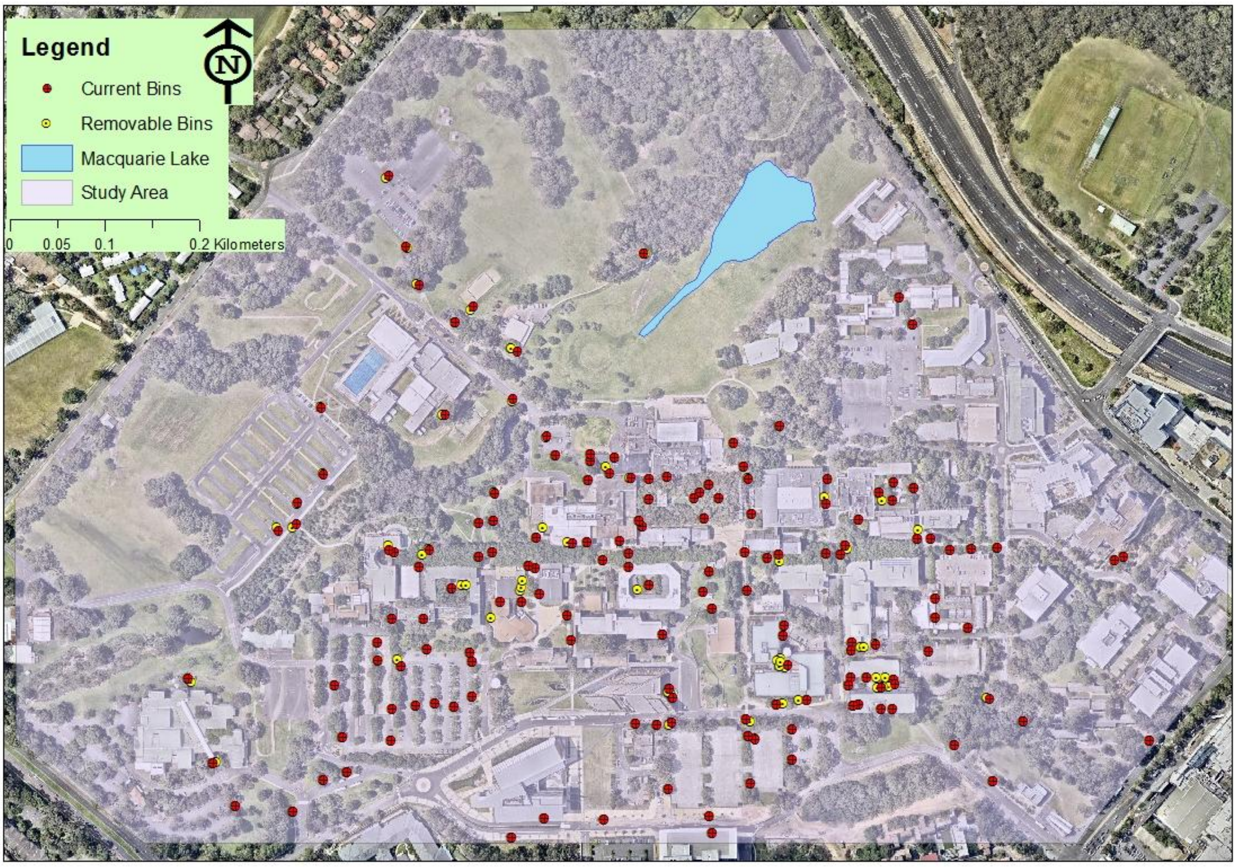
Appendix 11.5: Reducing 10% of bins (20) from current distribution of 194 litter bins using 'maximize attendance' problem type and considering population density at 400 meter impedance cut-off



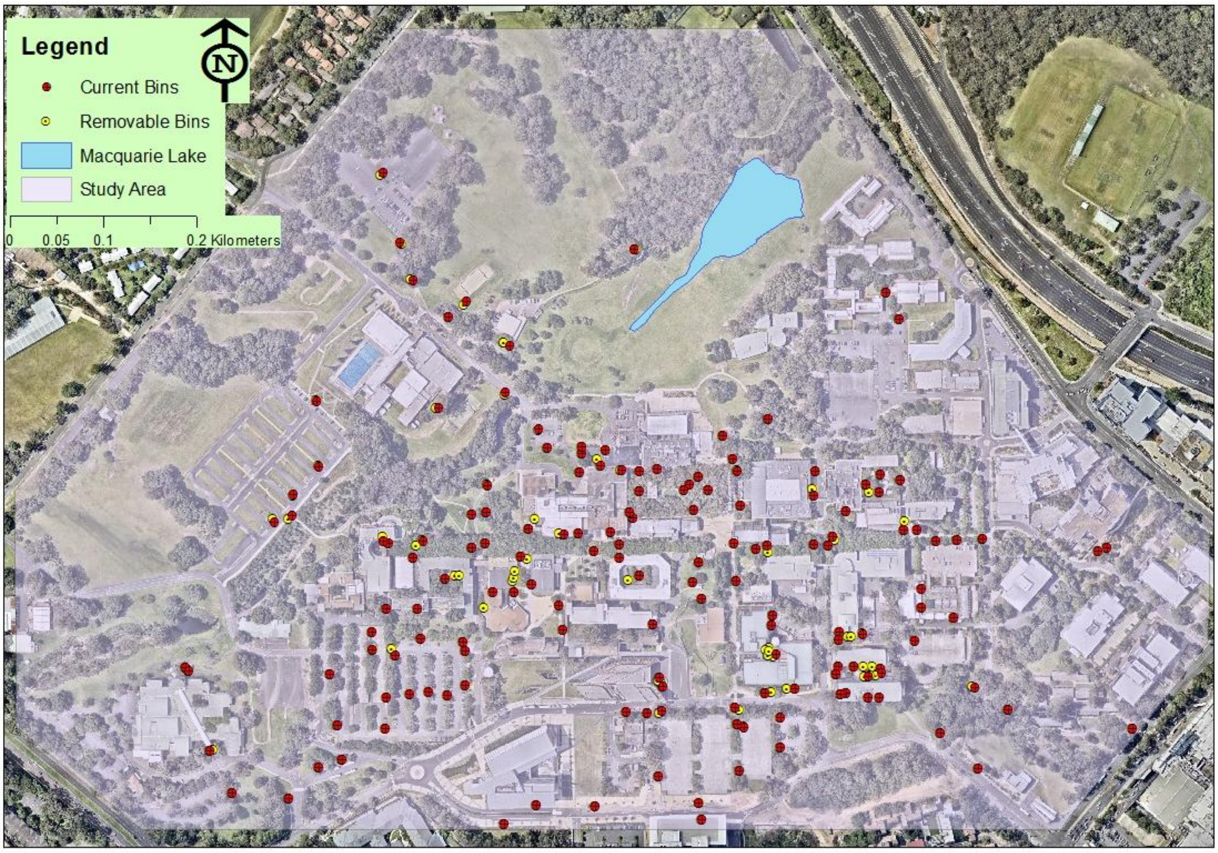
Appendix 12.1: Reducing 20% of bins (39) from current distribution of 194 litter bins using 'maximize attendance' problem type and considering population density at 38 meter impedance cut-off



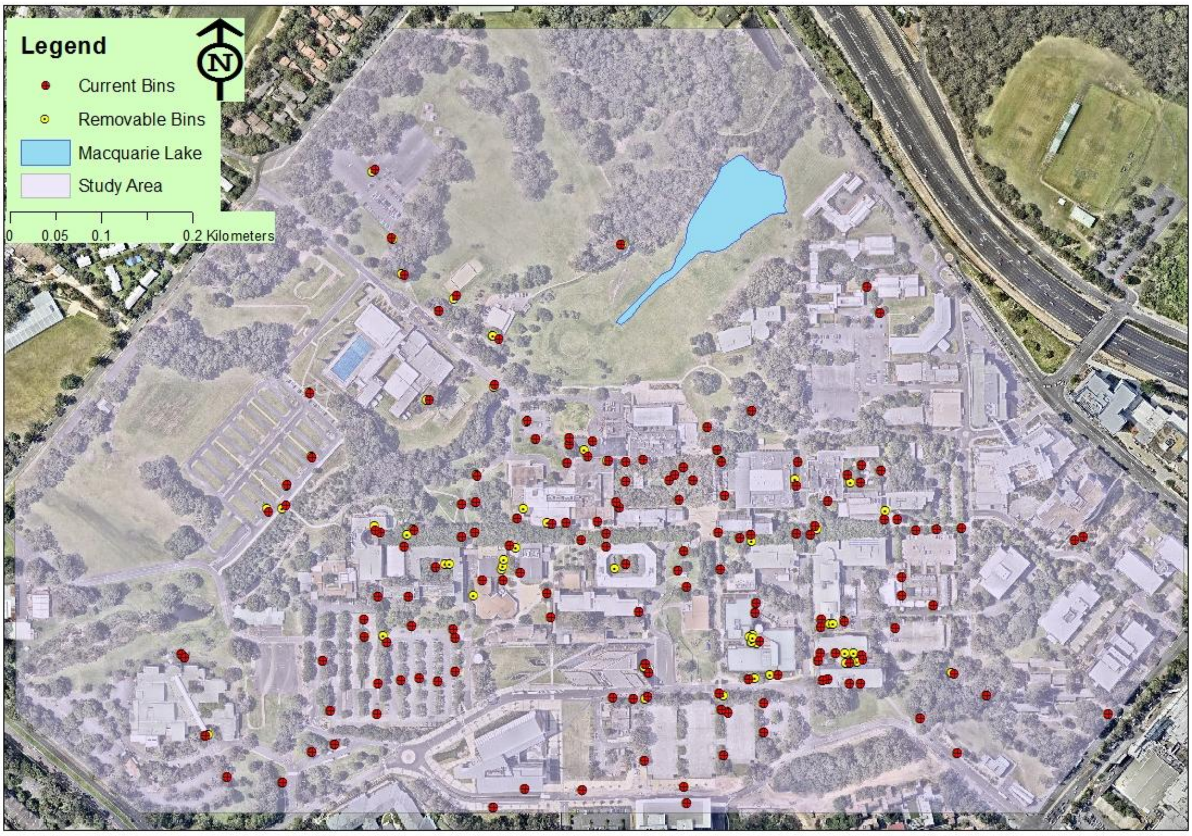
Appendix 12.2: Reducing 20% of bins (39) from current distribution of 194 litter bins using 'maximize attendance' problem type and considering population density at 52 meter impedance cut-off



Appendix 12.3: Reducing 20% of bins (39) from current distribution of 194 litter bins using 'maximize attendance' problem type and considering population density at 63 meter impedance cut-off



Appendix 12.4: Reducing 20% of bins (39) from current distribution of 194 litter bins using 'maximize attendance' problem type and considering population density at 80 meter impedance cut-off



Appendix 12.5: Reducing 10% of bins (39) from current distribution of 194 litter bins using 'maximize attendance' problem type and considering population density at 400 meter impedance cut-off