# Quantifying the historical evolution of green space in New Zealand's cities

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# Quantifying the historical evolution of green space in New Zealand's cities

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# Summary

## Project and client

The Parliamentary Commissioner for the Environment (PCE) contracted Manaaki Whenua – Landcare Research to investigate how best to measure changes in the amount and distribution of public and private green space in New Zealand cities through time. The methodology was applied to three cities: Hamilton, Auckland, and Wellington.

## Objectives

- Measure public and private green space in a subset of New Zealand Tier 1 cities and how these have changed over time.
- Identify how public and private green spaces are distributed within the three cities and how this has changed over time.
- Compare the results to the population distribution to derive the distribution of green space *per person.*

## Methods

A Geographical Information System (GIS)-based approach was used, with the following steps.

1 Select time periods with suitable aerial photography and make the imagery analysis-ready.
2 Decide the urban boundaries.
3 Generate population statistics.
4 Identify areas potentially containing public or private green space.
5 Detect buildings.
6 Create map layers.
7 Calculate the statistics.
8 Document the work in an illustrated report.

## Results

- Hamilton's population density increased by over 50% between 1940 and 2016, whereas the population densities of Auckland and Wellington remained almost constant over the same period.
- There have been substantial changes to the built form over the study period. All three cities were characterised in the 1940s by relatively high-density urban centres surrounded by lower-density developing areas at the boundary. Between 1940 and 1980 new greenfield residential development tended to be lower density than the urban centres, but between 1980 and 2016 new residential developments became significantly denser, and infill development accelerated. Of the three cities, Wellington is the least affected by these changes, probably owing to its steep topography.
- Total green space as a proportion of urban area in the three cities has declined since the 1940s, with the reduction varying from 0.6 to 14 percentage points, corresponding to a loss of green space of between 1 and 20% relative to 1940.

- Hamilton and Auckland have experienced the largest reduction in green space as a proportion of urban area.
- Wellington's green space as a proportion of urban area has only declined slightly. If the peri-urban reserves are included, the green space proportion of the urban area has remained almost constant.
- Public green space as a proportion of urban area has declined only slightly or remained constant for all three cities, but the proportion of private green space has declined more significantly.
- The amount of green space per person has declined the most in Hamilton, followed by Auckland. If peri-urban reserves are included, the amount of green space per person in Wellington has increased.
- Green space in Auckland and Wellington is mostly found at/near the city margins, while in Hamilton it is more evenly distributed.

**Conclusions**

- Based on these three North Island cities, urban populations are increasing at about the same rate as the cities expand so that the population density remains about the same.
- Public green space as a proportion of the urban area in all three cities has remained about the same, but the amount of private green space has reduced. This is driven by increased density of new subdivisions, infill housing in existing areas, and an increase in the amount of land being used for commercial purposes.
- The distribution of public green spaces varies: it is evenly distributed in Hamilton, but generally at/near the urban edges in the other two cities.
- Each city has had a different growth trajectory: Hamilton transitioned from a town to a city between 1940 and 1980, Auckland grew throughout, and the Wellington urban area is a mixture of areas of minimal change (Wellington City) and areas of greater transformation (Lower Hutt).
- All three cities have experienced significant intensification of the older (1940s) area because of housing intensification, industrialisation/commercialisation, and increased roading.

**Recommendations**

- Extend the study to the remaining two Tier 1 cities (Tauranga and Christchurch) and potentially some Tier 2 cities.
- Repeat the study for additional time periods when the aerial imagery becomes available.
- Enhance the methodology by measuring green space directly for the most recent imagery, including separating tree canopy from other green space, if possible, and analyse for trends (e.g. by sampling across areas that undertook development at different times).
- Further analyse the generated GIS layers for other insights, such as distance to public green space and tree canopy cover.

# 1 Introduction

The Parliamentary Commissioner for the Environment (PCE) contracted Manaaki Whenua-Landcare Research to investigate how best to measure changes in the amount of, and distribution of, public and private green spaces in New Zealand cities through time. The methodology was applied to three cities: Hamilton, Auckland, and the greater Wellington urban area.

# 2 Background

Green spaces in cities provide a variety of ecosystem functions and services spanning environmental, societal, and economic benefits. They comprise public green spaces such as parks, community gardens, golf courses, schools and cemeteries, and private green spaces such as individual residential sections and gardens.

New Zealand needs to improve and increase its housing stock to accommodate population growth. This need for more housing can be met by concentrating the population via infill housing, townhouses, and apartments, and/or by allowing the cities to expand over the (usually agricultural) surrounding land. With concentration of housing stock there is a risk that there will be a consequent decrease in the public, and private, urban green spaces. Conversely, expanding over the surrounding land has the potential to *increase* the amount of open space available, but at the expense of a loss of productive land.

We seek to understand how the provision of public and private open spaces has changed over time in three major New Zealand cities from 1940 to 2016. These cities were selected in consultation with PCE based on size, representativeness, and data availability.

# 3 Objectives

The objective of this study is to measure the change in public and private green space in three of the five Tier 1 cities in New Zealand: Hamilton, Auckland, and Greater Wellington (Wellington city, Lower Hutt, Upper Hutt, and Porirua). A second objective is to identify the distribution of urban green space within the three cities and how this has changed over time. Thirdly, this information is compared to the population distribution to derive the proportion of green space *per person*.

For the purposes of this study, green space consists of a mixture of natural space (grass, trees, and shrubs) and 'grey' space (paved areas such as playing courts, courtyards and plazas, patios, and driveways). This is largely due to methodological constraints: though it is possible to separate (and therefore measure) green and grey space from modern colour aerial imagery, only monochromatic imagery is available for the historical areas. The quality of this imagery is insufficient to distinguish green from grey space in every case.

To capture trends in green space over time, three time periods were studied: the 1940s, 1980s, and late 2010s. The actual years used varied between the cities depending on available imagery and population statistics.

## 4 Methods

A Geographical Information System (GIS)-based approach was used in this study. Initially an attempt was made to map green space directly using machine learning techniques to separate green and impervious areas. However, this proved to be not feasible to the required accuracy from the available black-and-white imagery.

Instead, a 'subtraction' approach was used to map green space by identifying – and removing – surface types that are not green: buildings, transport corridors, and commercial/industrial areas. This process involved considerable manual analyst input and is far from perfect. Some areas of grey space (largely residential driveways and patios) could not be practically identified and removed manually, and so have been included in the analysis as green space. For the same reason, some areas of green space (roadside berms being the most important) have been excluded from the analysis.

Starting with current territorial authority zoning maps, we manually modified maps to reflect the situation for the historical periods, so far as this was practical. We then used machine learning techniques to detect buildings in the historical images, resulting in a building map that was used to mask out the building footprints from the identified open space zones, giving a method of measuring green space that was sufficiently consistent across the current and historical periods.

Urban green space for each of the cities was estimated by generating public[1] and private green space binary GIS raster layers. These were then converted into percentages of green space for a given region (using zonal statistics), and green space per person was calculated.

A six-step procedure was carried out for each period.

1 Select suitable imagery.

2 Define the urban boundary.

3 Segment the urban area into public and private space regions and exclude areas that do not contain significant green space, including commercial/industrial zones, transport corridors, water bodies, and structures such as wharves.

[1] For the purposes of this study, public green space means areas containing significant green space that are generally available to the public, including both land zoned as open space in the territorial authority maps and other facilities generally open to the public such as schools, universities, hospitals, sports facilities and golf courses.

4 Detect buildings in historical imagery and subtract their footprints from the public and private open space areas, leaving the green space (as defined previously).

5 Calculate the proportion of public and private green space for the urban area as a whole and for Stats NZ Statistical Area Units (SAUs).

6 Calculate the green space available per person (per SAU and the whole city).

All calculations for area are based on the orthographic projection of the land surface; i.e. topography is not taken into account, since this is the convention in surveying and mapping.

## 4.1 Imagery/data selection

Although the first aerial photograph in New Zealand dates back to 1919, aerial photographic surveying before the 1930s was practically non-existent. Since then historical aerial photography remained uncommon, although the frequency of aerial photography flights over urban areas has improved over the last decade or so.

Local authorities collect aerial photography of their urban areas, but until recently there has been no nationally organised data collection. This is changing now that the Land Information New Zealand (LINZ) Data Service[2] is taking on a coordinating and curating role. This involves a programme of scanning and digitising historical imagery. LINZ are also making New Zealand's most current publicly owned aerial imagery – covering 95% of the country – freely available to use under an open licence.

Nonetheless, the dates and quality of available imagery over any given city can be variable. Early aerial photographic surveys are monochrome. Colour aerial photography was first collected in the mid-1930s, but it only became relatively common in New Zealand in the late 1980s. This century, aerial photographs are typically digital, and both natural colour (blue, green, red) and (less commonly) near infrared data are collected. Historical imagery was obtained by querying the Retrolens online database,[3] identifying the most suitable images, and then obtaining the original image scans from LINZ.

We examined the historical imagery available on Retrolens and settled on the data sets listed in Table 1, based on obtaining full coverage at sufficient resolution and the availability of population data.

[2] https://www.linz.govt.nz/data/linz-data-service

[3] https://retrolens.co.nz

**Table 1. Details of the aerial photographs**

| City | 1940s imagery details | 1980s imagery details | 2010s imagery details |
|---|---|---|---|
| Auckland | 1940 monochrome 0.25 m | 1980 monochrome 0.25 m | 2017 colour, digital 0.075 m rescaled to 0.3 m |
| Hamilton | 1943 monochrome 0.25 m | 1979 monochrome 0.25 m | 2016–2019 colour digital, 0.3 m resolution |
| Wellington | 1941 monochrome 0.25 m | 1980 monochrome 0.25 m | 2016–2017 colour, digital 0.3 m resolution |

## 4.2 Defining the urban boundary

There is no official definition of the urban–rural boundary for the three time periods studied. Stats NZ define 'functional urban areas', which group urban areas where people live, work, shop and play. They are based on the urban–rural classification (2018) and commuting patterns of SA1s.[4] Using functional urban areas to define the boundary is problematic because they are often based on territorial boundaries, and these may include significant areas of (functionally) rural land zoned for future development: not only do these areas inflate the amount of green space, but they also cannot be replicated for the historical periods.

Instead, the boundaries used for this study were created through visual inspection of aerial imagery. Areas of contiguous urban development were included, while 'strip' residential developments along individual roadways were left out. Also:

- where public reserves exist adjacent to the built boundary they have been included
- where a natural boundary exists that is close to the built boundary, such as a waterway or coastline, the boundary is extended to it.

This process was repeated for all three periods to give the final boundary. Wellington is a special case because, from 1980 onwards, it began to be surrounded by large, new peri-urban reserves, which comprise a significant proportion of the public green space. The approach we adopted, in consultation with PCE, was to report Wellington statistics both including and excluding these peri-urban reserves.

A potentially significant issue with the urban boundary selection employed here is the over-representation of the amount of undeveloped private land that is included within the boundary. This can result from two causes.

- The urban area is very low density early in its development. This is especially true for Hamilton, which was still a provincial town in 1940. In contrast, both Wellington and Auckland were well-developed cities by 1940.

[4] Statistical area 1s (SA1s) are used by Stats NZ to classify parts of urban or rural areas. An SA1 contains 100–200 residents.

- Natural features prevent development of some areas within the boundary; this is particularly true of Wellington.

We discuss this effect further when reporting the results.

## 4.3 Generating aerial image mosaics

We produced aerial mosaics for each of the cities using the aerial imagery supplied by LINZ. For 2016 the mosaics were already available, while for the historical periods we processed scanned black-and-white imagery.

The mosaicking was performed using ESRI's ArcGIS Pro, which enables sets of scanned images to be orthorectified, radiometrically matched, and blended at the seamlines between individual images. Metadata available with the imagery are used to define the imagery focal length, scale, flying altitude, scanning resolution, flight line, and nominal geographical position at the centre of the image. The flight line direction is calculated from the sequence of image locations, and from this individual image orientations are estimated.

Ideally the above locational data are accurate enough to roughly position the images both with respect to each other and in an absolute sense with respect to an appropriate base map. The ArcGIS Pro mosaicking package can then automatically search for tie points in the overlapping areas between images using correlation techniques, and once sufficient are found a block adjustment calculation is done to locate all the images with respect to each other. At this point a number of ground control points (GCPs) are identified in both the scanned imagery and in a suitable base map to enable the block-adjusted imagery to be located absolutely with the map. A digital terrain model is also used in this step to enable true orthorectification of the individual images. GCPs are not required for every individual image but should be spread around the mosaic. A current aerial photographic ortho-mosaic was used as the base map, and given the historical nature of the imagery, GCPs were most commonly identified at the centre of road intersections.

Once the image collection is orthorectified, ArcGIS Pro can match the imagery in the overlap areas, identify a set of seamlines along the overlap centres, and feather the imagery together across a small number of pixels either side. A mosaic image is then interpolated from the component orthorectified images using a pixel spacing of 0.25 m.

The component photography used in each mosaic is shown in

Table 2. Unfortunately, the metadata associated with some of this photography were too inaccurate to allow ArcGIS Pro to find tie points between the photo frames. This was particularly an issue in the 1940s imagery and worst over Wellington. Image centres were sometimes out by several kilometres, and the true position was not even within the nominal image footprint. This, along with variable flying heights, made it impossible to mosaic the imagery automatically.

**Table 2. Component photography**

| Mosaic (main image date) | Aerial images | Scale | Scan resolution (microns) |
|---|---|---|---|
| Auckland 1942 | 244 | 1:16,000 or 1:10,800 | 21 |
| Auckland 1980 | 74 | 1:25,000 | 14 |
| Hamilton 1943 | 18 | 1:16,000 | 21 |
| Hamilton 1979 | 13 | 1:25,000 | 14 |
| Wellington 1941 | 174 | 1:16,000 | 21 |
| Wellington 1980 | 61 | 1:25,000 | 14 |

Smaller blocks of imagery – sometimes a single flight line or part flight line – were mosaicked and properly located using GCPs. Each photograph's actual centre position, orientation, and scale were then recorded and later substituted for the provided metadata to create a photo layout accurate enough for ArcGIS Pro to process. The process was somewhat iterative as larger groups of imagery were successfully aligned and located. Some manual identification of tie points was required, and many more GCPs were used than would normally be required for a single mosaic.

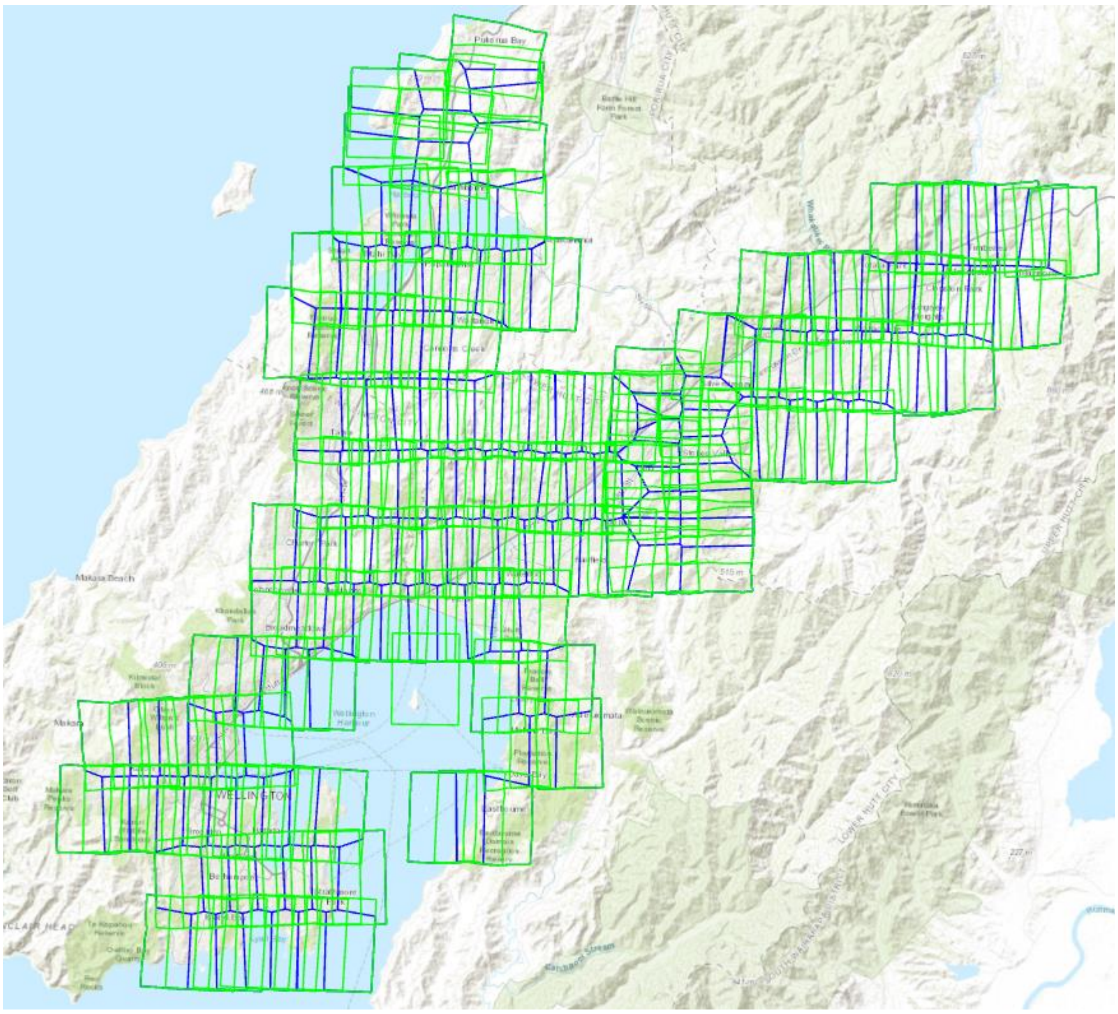

**Figure 1. Photo layout for Wellington 1941 mosaic, with footprints in green and seamlines in blue.**

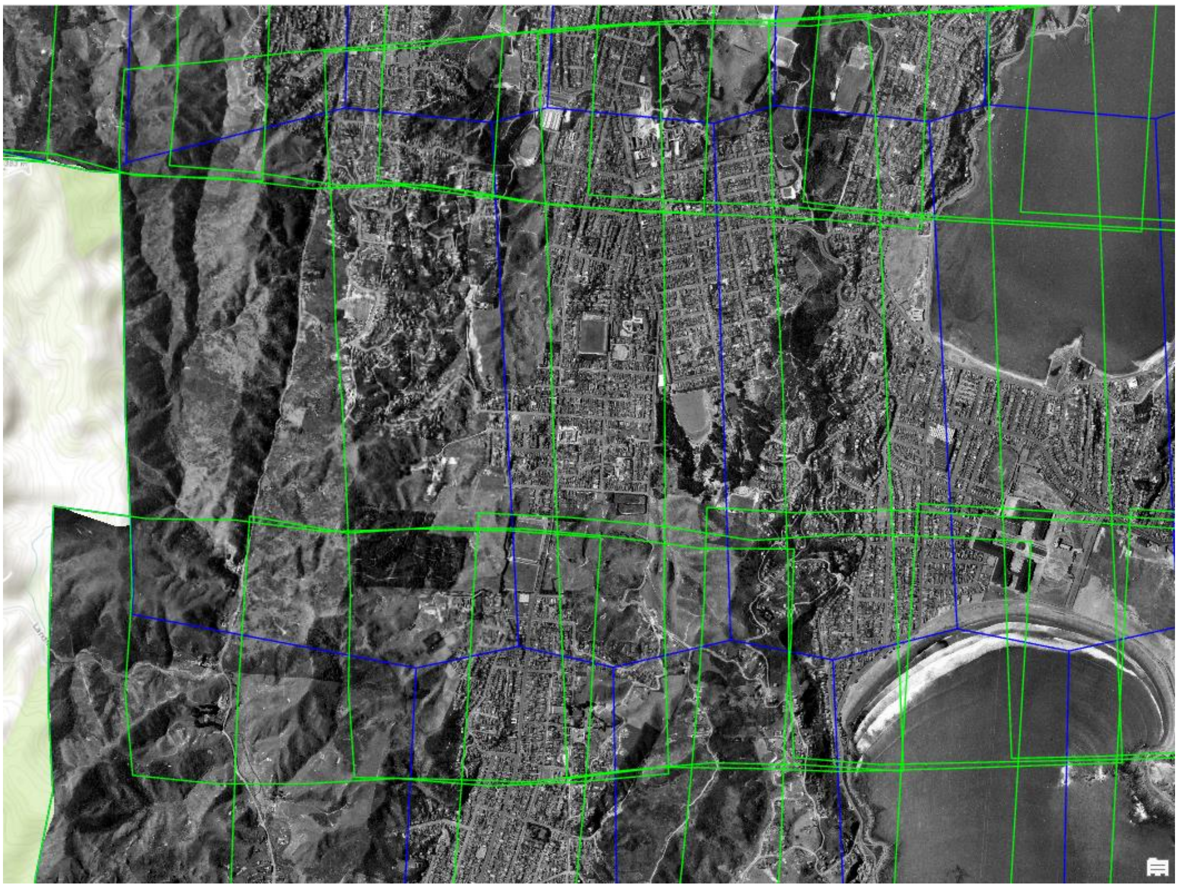

**Figure 2. Detail over Wellington City, showing that the footprint edges are not straight due to terrain and the orthorectification process.**

## 4.4 Generating population statistics layers

To analyse the distribution of green space per person, we created population counts and densities for each of the Stats NZ SAUs using the following process.

1. Acquire population values from Stats NZ to the meshblock level.
2. Clip the meshblocks to the urban boundary and calculate the clipped area and population density of each meshblock.
3. For clipped meshblocks, multiply the meshblock densities by their area to get their estimated population.
4. Aggregate meshblock populations to SAUs.

For 2016 and the 1980s population statistics were obtained for meshblocks (as defined at the relevant census) from Stats NZ. No such data exist for the 1940s, so the following approach was adopted.

1 Obtain population statistics for the earliest period for which the population is broken down into zones. For Hamilton and Wellington, population figures were available for 1951, broken down to inner and outer city for Hamilton and boroughs/districts for Wellington; for Auckland the 1940 population was reported by borough.

2 For each zone, calculate the percentage of the population in each meshblock based on the oldest meshblock population distribution available (typically 1980s).

3 Calculate the population in each meshblock by multiplying the meshblock percentage by the population for the historical zone.

It should be stressed that the above process is an approximation and relies on the assumption that the later population distribution is a reasonable proxy for the distribution in the earlier period. This assumption is unlikely to always be correct. For Hamilton, an additional source of error is that the population statistics used were from 1951. On clipping the resulting meshblocks back to the selected 1943 boundary, the total included population was estimated at 16,099, compared to the official figure for the Hamilton urban area of 16,150 in 1936 and 29,838 in 1951. As Figure 3 shows, Hamilton grew significantly between 1943 and 1951, corresponding to an almost doubling of its population during this time, and the entire area studied for 1943 is substantially smaller than the 1951 city boundary. This growth probably happened post-war, which is supported by research.[5]

- Hamilton's boundaries were extended from the late 1940s and had more than doubled by 1962, a consequence of post-war population growth, which surpassed that of other provincial cities.
- There were 21,982 people residing in Hamilton by 1945, the year it gained city status.

[5] https://teara.govt.nz/en/waikato-places/page-7

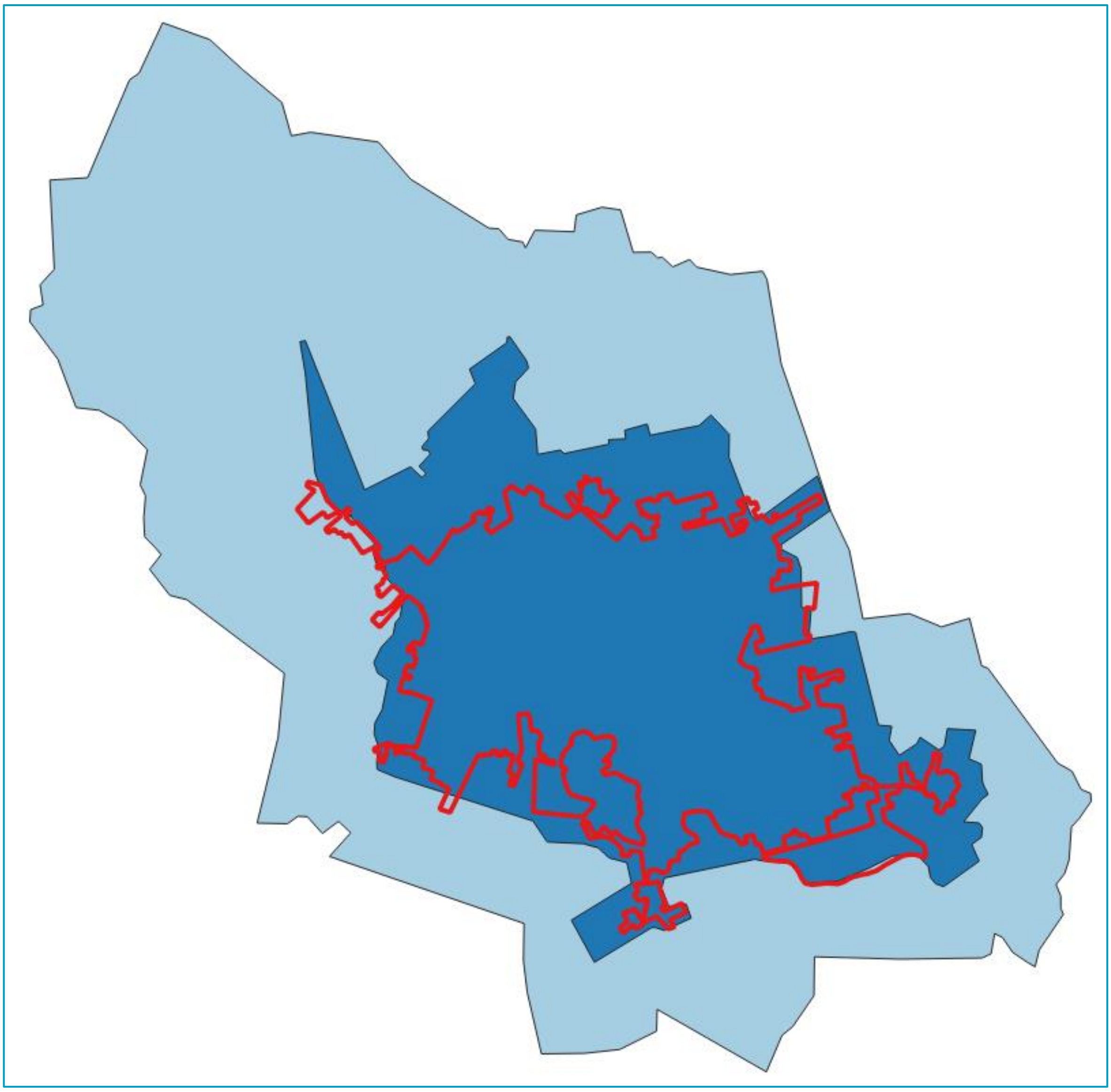

**Figure 3. Selected Hamilton 1943 boundary (red) compared to the 1951 census boundaries. The city boundary is in blue and the urban area boundary in light blue.**

## 4.5 Identifying potential green space areas

As a first step in the mapping of open space, each city was segmented into one of seven land-use classes: public open space, peri-urban public open space (Wellington only), private land, commercial and industrial, transport corridor, water, and 'excluded'. The excluded category was used for areas that, while within the urban boundary, were not accessible green space, such as tidal mudflats and areas zoned for future development (in practice the latter were almost entirely removed through selection of the boundary).

For 2016 this was done using the zoning maps of the relevant territorial authorities, all of which were obtained from the relevant councils as GIS layers. Some maps excluded roads from their planning zones, while others did not; the latter were amended by subtracting the areas covered by the New Zealand Road layer.[6]

The resulting GIS layers were then manually verified and updated to correct for the following issues, for both 2016 and the historical periods.

1. Roads that did not exist in a given period were removed and missing roads added.
2. Areas of public open space, private space, and commercial/industrial space were refined for historical periods to allow for land-use change over time. This was done by manually inspecting the aerial imagery and reclassifying where necessary. A common issue was that many of today's commercial/industrial areas were either undeveloped open space or residential in earlier periods.
3. Public/private ownership/access was refined based on a combination of visual inspection and research into reserve creation dates.
4. Green space versus built-up (extensively paved) space was refined to include green areas within industrial/commercial zones, and to exclude significant paved areas (such as large car parks) from open space zones.

We recognise that this open space classification is not perfect, particularly for the historical periods. In particular, the separation of public and private open space is difficult given the impracticality of researching the history of every reserve in a large city such as Auckland. Further, while best efforts have been made to ensure details such as roads and significant paved areas are accurately mapped, there may be some errors. However, their influence on the final statistics should not be large.

## 4.6 Detecting buildings

Buildings were detected and mapped for each city and period by training a supervised deep convolutional neural network[7] to segment aerial images into built/unbuilt. This method works by detecting patterns in imagery that correctly predict the class (built or unbuilt) of every pixel in an aerial image. To train the model, a 'ground truth' output mask is needed. For the 2016 mosaic, the NZ building outlines layer[8] was used to generate the mask.

Further training data were required for the earlier periods. This is because while, in theory, a model trained on modern imagery might also serve for the past imagery, in practice

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[6] https://data.linz.govt.nz/layer/53378-nz-roads-road-section-geometry/

[7] Y Bengio 2009. Learning deep architectures for AI. Foundations and Trends in Machine Learning 2(1): 1–127. CiteSeerX 10.1.1.701.9550. doi:10.1561/2200000006

[8] https://data.linz.govt.nz/layer/101290-nz-building-outlines/

there were major differences in image characteristics between the modern and historical imagery, as well as between the 1940s and 1980s historical imagery, including the following.

- Modern images are digital, whereas the historical imagery comprises photographs that have subsequently been scanned. These contain significant 'grain' patterns that confuse the model.
- Brightness and contrast vary between periods. Whereas the modern imagery is normalised, the 1980s images are brighter and with lower contrast, while the 1940s imagery is much darker, with highly variable contrast levels even within a single mosaic, as well as within individual photographs from lens falloff.
- Focus accuracy is poor for many of the historical images (and varies across a single mosaic and, to a lesser extent, individual photos).
- Many of the historical prints contained damage, including scratches, mould, fingerprints, and other marks.
- The *built form* has changed over time, meaning a model based on modern imagery may not recognise buildings in the historical images.

To overcome these issues, *imperfect* training data for the historical periods were added to the training set. To produce these imperfect training data, we selected areas of the cities that had changed relatively little between the historical time interval and the present day (Wellington 1940s and 1980s; Hamilton 1980s).

Although the amount of historical training data is much less than for the more accurate 2016 data, its inclusion significantly improves the performance of the model on the historical imagery without overly affecting the model's accuracy overall. However, we note that the building detection is far from perfect. This is due to the relative dearth of suitable training data and the poor quality of the historical imagery. The 1940s imagery was the worst affected, causing a reduction in both precision and recall (false positives and missed buildings, respectively). Another compounding problem is the difficulty of accurately geolocating the historical images, again, particularly for the 1940s images, because of complex distortions in the images. There are two consequences of this.

1 Some areas of the building masks are offset relative to the open space classification layer, introducing errors when the two are combined. These errors include building footprints falling partly outside the open space zone they belong to.

2 The deep learning model becomes less precise because the training image and label (based on the LINZ building footprints) do not align, causing the class of the building edges to appear ambiguous. The resulting building footprints then become less well defined, with rounded corners.

Although these issues affect the precision of the resulting mask, in practice this error is small compared to other sources (this is discussed in section 4.8).

## 4.7 Calculating green space area

The building masks were used to calculate green space area as follows.

1 Invert the building mask to create an 'unbuilt' mask.

2 Clip the mask to the city areas classified as public and private open space, giving a public green mask and private green mask.

3 For each SAU, calculate the mean value for the public and private unbuilt masks, giving the proportion of the SAU that is public or private green space (i.e. green space proportion or density).

4 Compute other statistics for each SAU, including the total green space percentage and public, private, and total green space by population ($m^2$ per person).

5 Calculate the area (in $m^2$) of public and private green space for each SAU and aggregate to give summary statistics for the whole city by dividing each sum by the corresponding denominator (total city area for green space percentage by area; total population for green space per person).

## 4.8 Assumptions and limitations

This research relies on many assumptions and approximations that limit the accuracy of the results. Table 3 summarises known sources of potential error, their potential impact, and the steps taken to mitigate them.

**Table 3. Issues affecting the accuracy of the calculated results and their mitigation**

| Issue | Potential impact | Mitigation |
|---|---|---|
| Boundary selection is subjective. | Medium (affects percentage coverage calculations only) | Boundaries generated by 2 independent researchers with high overall agreement and consistent differences that could be resolved in consultation with PCE.<br>PCE consulted on boundary decisions, with generally high levels of agreement, and consistent changes requested.<br>Included comparison with fixed (1940s) boundary. |
| Classification decisions for commercial/industrial areas are subjective. | Medium | Classification agreed in consultation with PCE. Generally there was high agreement between the 2 parties. |
| Public versus private classification difficult for historical periods. | Medium | Classification based on the land use rather than ownership.<br>Classification decisions reviewed by PCE, with high agreement between the 2 parties. |
| Road corridors contain green space, which varies over time. | Medium | Road corridors excluded for all periods.<br>Green space in road berms may balance the grey space on private property. |
| Inaccuracies in the building masks. | High | Manual inspection of generated masks and refinement of process to maximise accuracy.<br>Assessment of mask accuracy on measured space. |
| Population of SAUs for 1940s uses an assumed distribution. | Low | Affects per-person distributions for 1940s only.<br>Inferred total population cross-checked against published statistics with good agreement/plausibility. |

# 5 Results

The following GIS layers were produced for each city and period:

- urban boundary
- potential green space classification layer
- public and private green space layers
- population and green space density statistics based on SAUs.

## 5.1 Overview of findings

In all three cities the amount of urban green space has changed over the study period, with the amount and direction of change differing depending on whether total green space area or green space per person is considered.


**Figure 4. Public and private green space summary (% of urban area).**

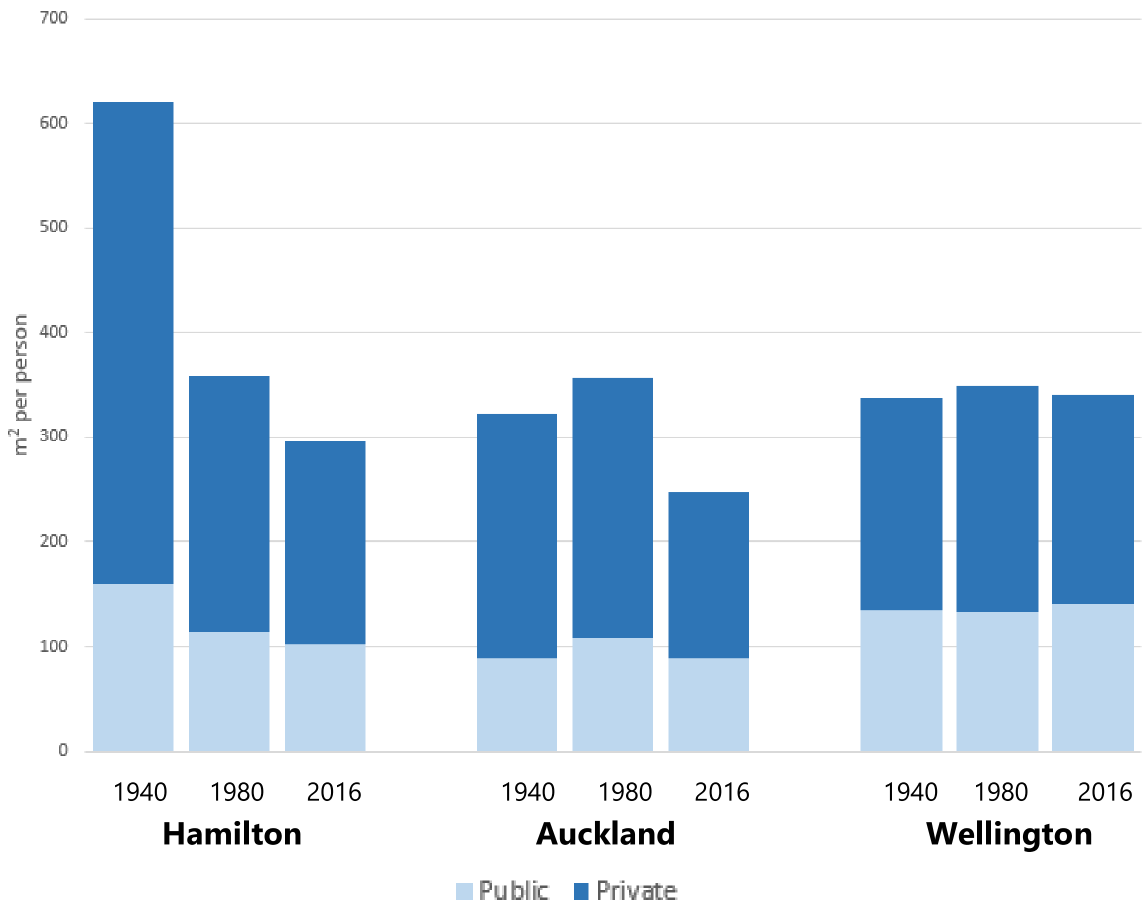


**Figure 5. Public and private green space summary by population ($m^2$ per person).**

### 5.1.1 Total urban area

The urban area of each of the three cities has grown markedly over time. Auckland and Hamilton grew by more than five times in area between 1940 and 2016, and Wellington by more than three.

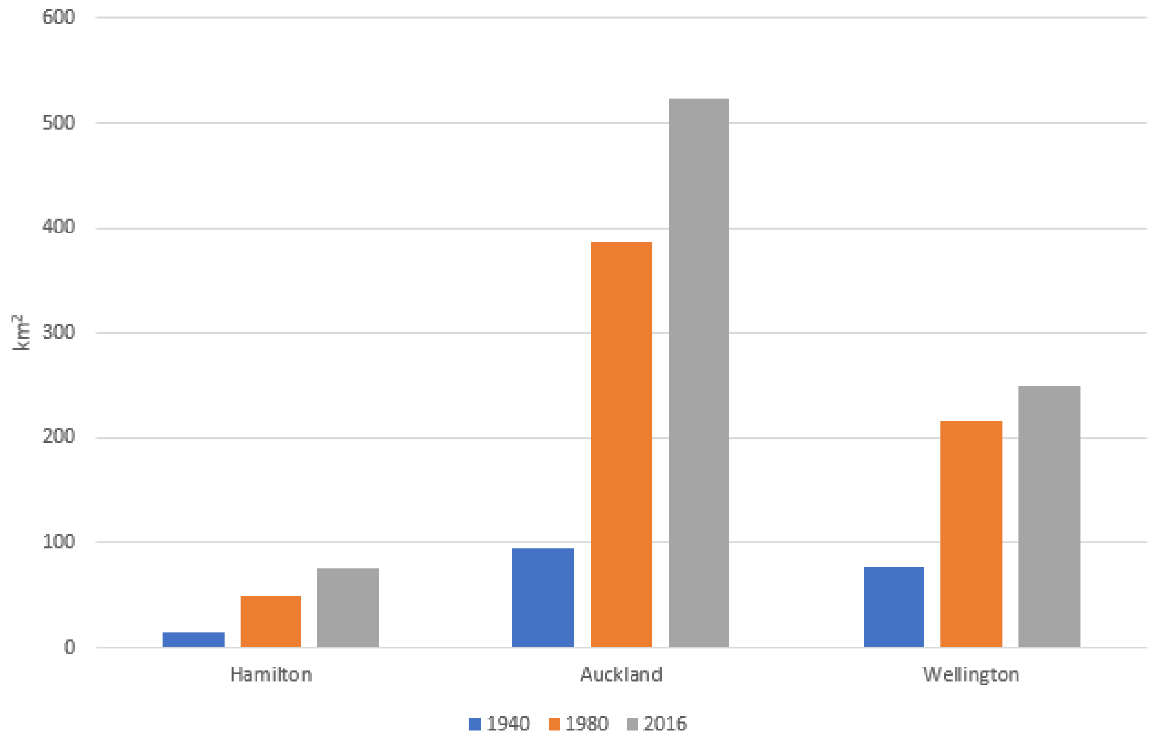


**Figure 6. Urban boundary area over time for the three cities (km²).**

### 5.1.2 Total green space as a proportion of total urban area

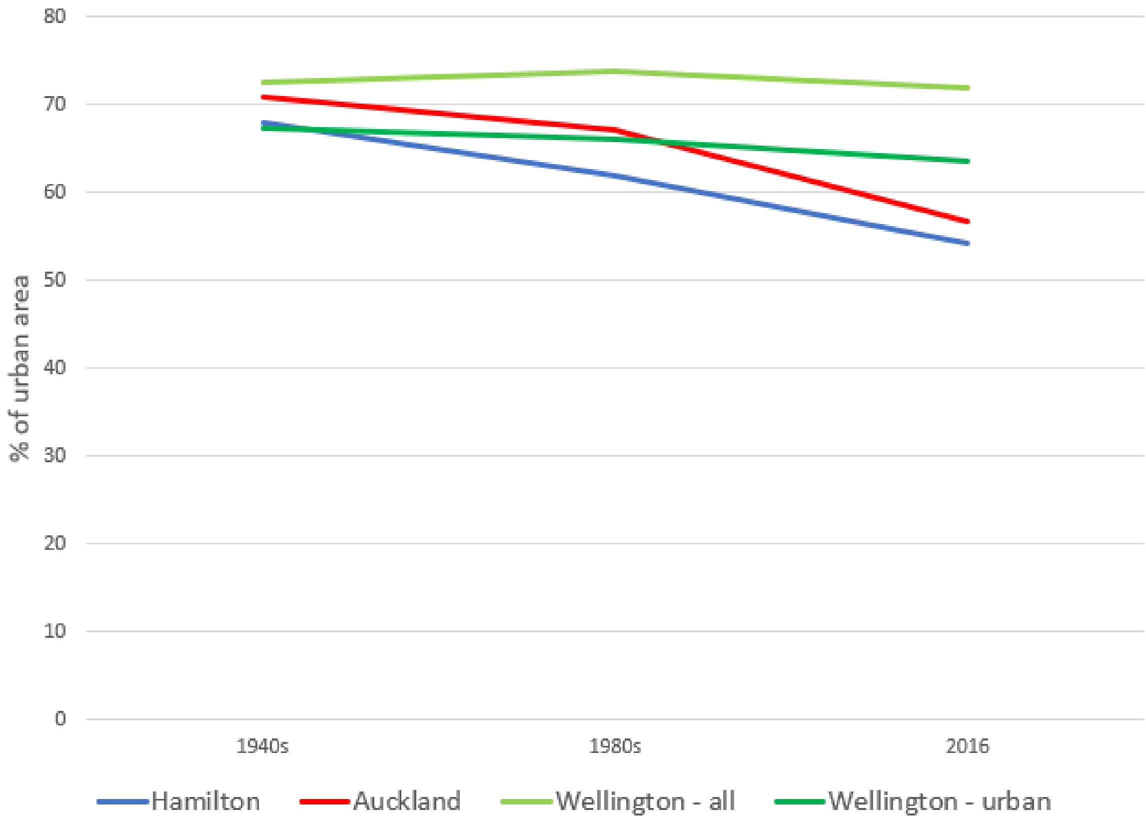


**Figure 7. Total green space (% of urban area) over time**

All three cities studied had similar amounts of green space (taken as proportion of their total urban areas) in the 1940s: around 70% (Figure 7). Since then, this proportion has declined in both Auckland and Hamilton, despite both cites growing in area considerably (see Figure 6). By 2016 Auckland had only 57% open space, a 14 percentage point reduction (20% reduction of the 1940 area), and Hamilton 54%, also a 20% reduction.

In contrast, Wellington has been on a different trajectory – essentially maintaining its proportion of total open space over time, if peri-urban reserves (mostly added from 1980 onwards) are included, or losing only 4 percentage points (6% of the 1940 area) by 2016 if they are excluded.

### 5.1.3 Total public and private open space as a proportion of total urban area

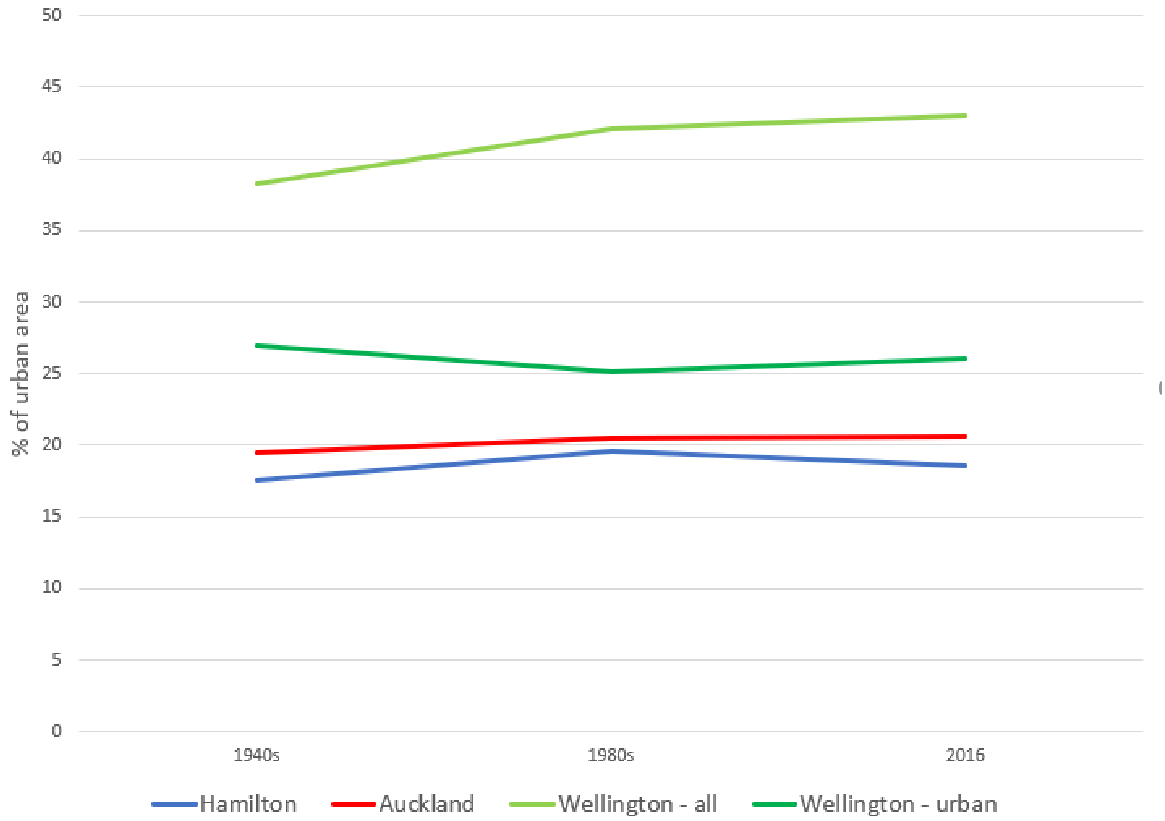


**Figure 8. Public green space (% of urban area) over time.**

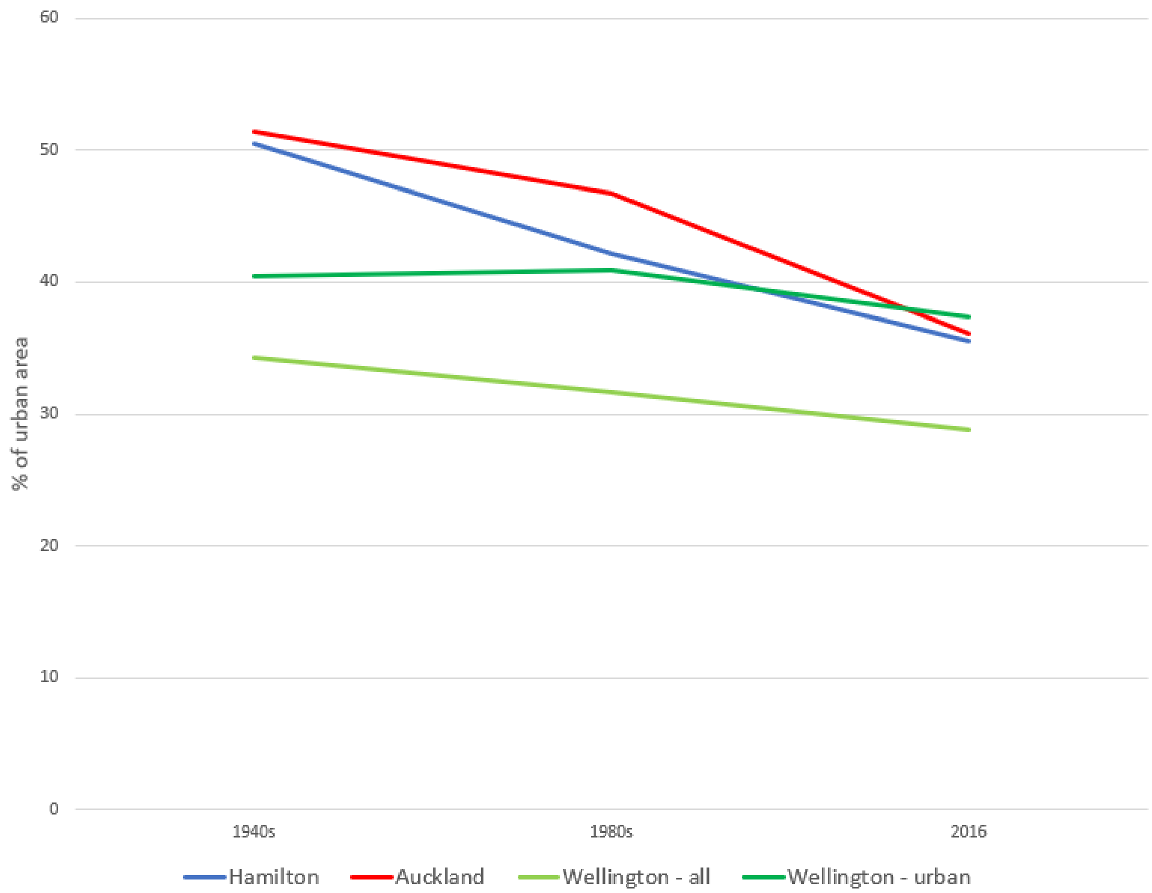


**Figure 9. Private green space (% of urban area) over time.**

Total public green space has been roughly static for all three cities (and increasing somewhat for Wellington if peri-urban reserves are included), while total private green space has declined in all three cases, with Wellington experiencing a more modest decline (Figures 8 and 9).

### 5.1.4 Green space per person

The amount of green space per person, when measured across the entire urban area, has changed considerably in Hamilton over time, and less so in Auckland and Wellington (Figure 10).

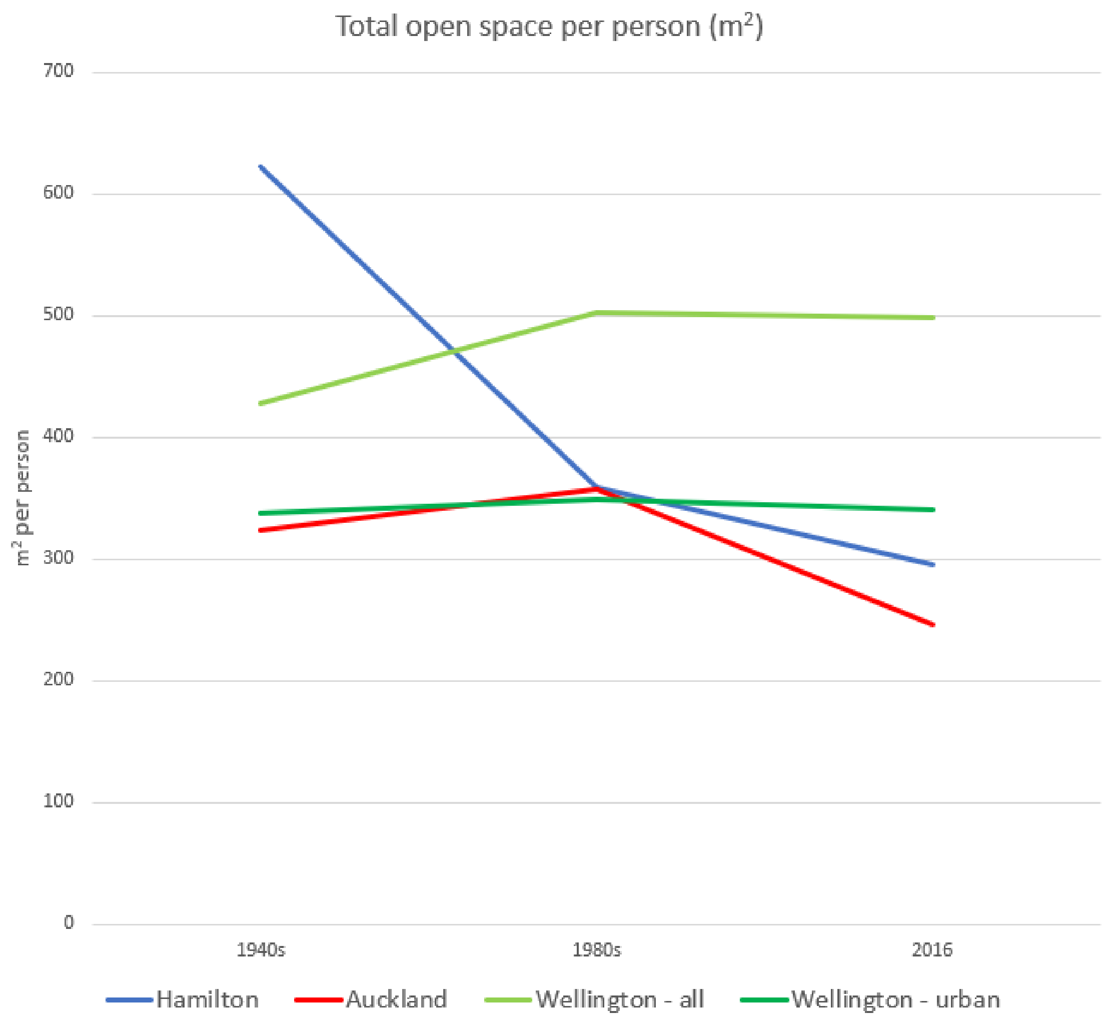


**Figure 10. Total green space by population (m² per person) over time.**

Hamilton saw a large decline in available green space per person, with it more than halving between 1940 and 2016. Auckland experienced a more modest decline, and urban Wellington has remained static, with the green space per person actually *rising* if peri-urban reserves are included. We note that most of Hamilton's steep decline occurs between the 1940s and 1980s, when it was transitioning from a provincial town to a city.

Figure 11 illustrates how Hamilton's built form has become much denser, particularly between the 1940s and 1980s, while large areas of Wellington have changed only modestly, reflecting a much higher built density originally, most likely driven by the finite amount of buildable land available because of the difficult terrain.  Hamilton's population density increased by over 50% between 1940 and 1980; Auckland's population density has remained largely static over the study period; Wellington's population density has *decreased* slightly.

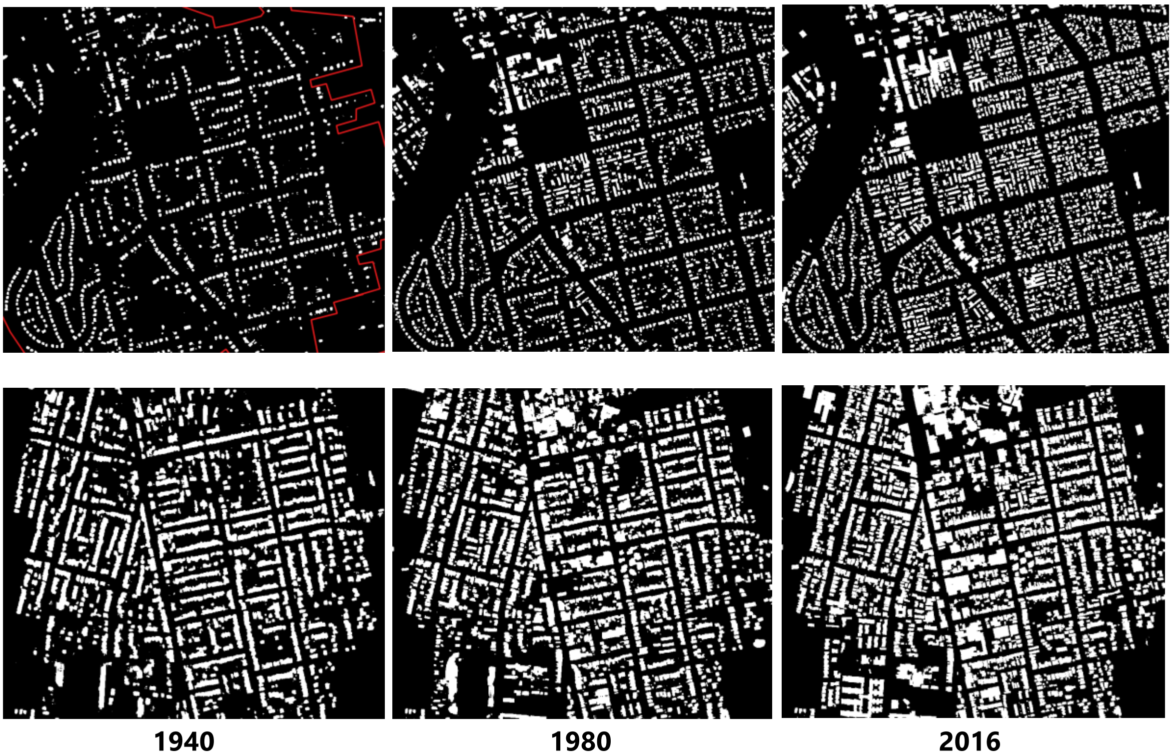


**Figure 11. Examples of changing built form: top line: Hamilton (East); bottom line: Wellington (Newtown).**

Another difference is the amount of *undeveloped* private space within the urban boundary. Hamilton was a provincial town in 1940, with residential properties developing along roads radiating out from the centre. As a result, the urban boundary encompasses large areas of completely undeveloped land which, by 2016, had been almost entirely developed. In contrast, Wellington's settlement pattern is defined by its steep topography, with housing developing along ridgelines. This has meant that, as Wellington has expanded, it has maintained a relatively constant proportion of private property that is undeveloped or only sparsely developed because it is too steep.

Green space density varies across each city, as shown in Figure 12, with some suburbs much denser than others. In Auckland and Wellington, green space is concentrated around the margins, where residential density is lowest, while Hamilton has its green space more diffusely distributed. This includes green spaces along the Waikato River, which flows through the city centre.

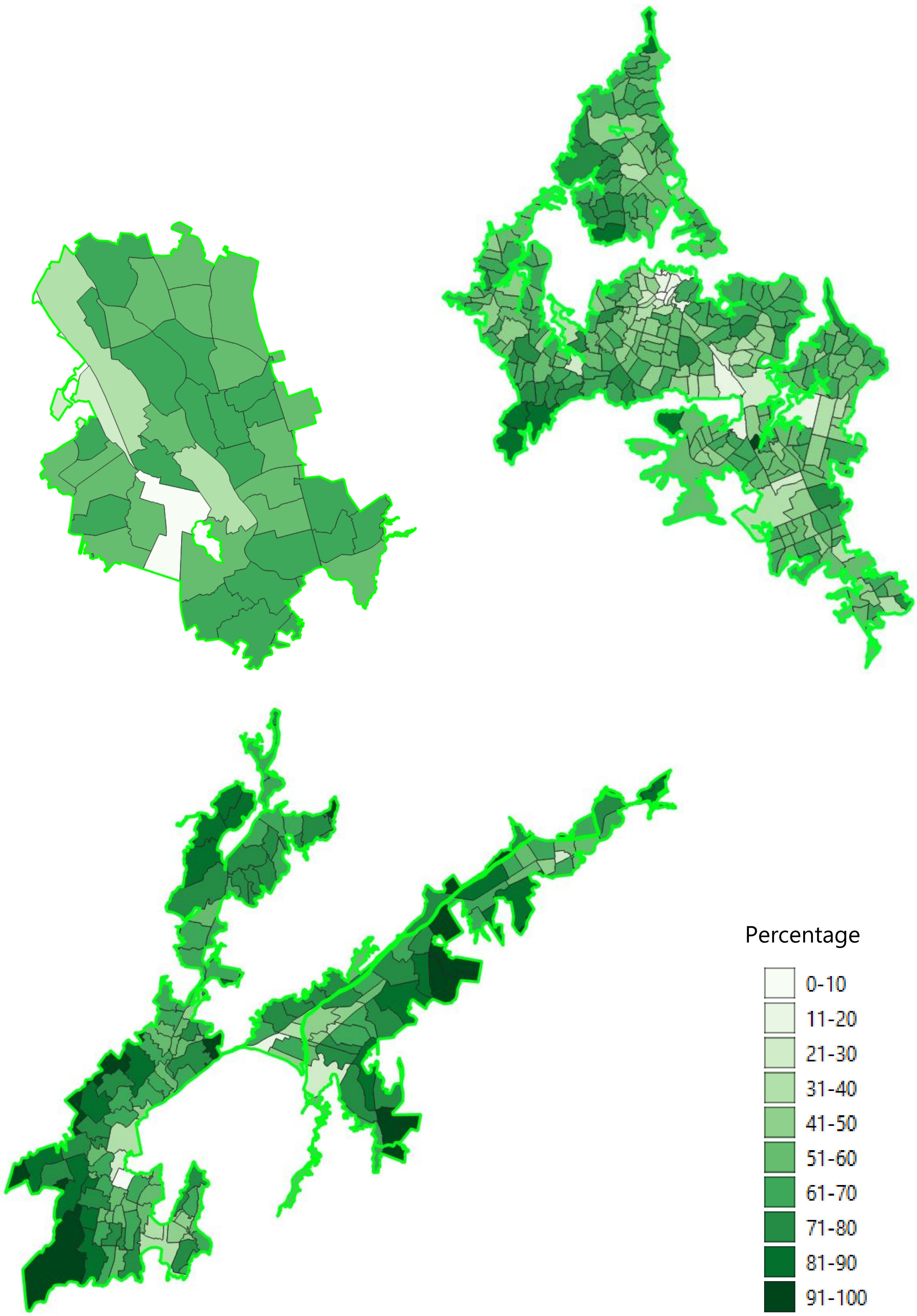


**Figure 12. Green space distribution in 2016 for Hamilton (top left), Auckland (top right) and Wellington (bottom).**

When looking at just the urban area that existed in the 1940s to see how it has changed, all three cities have undergone intensification of this area, resulting in a loss of green space, but the pattern is different for each city.

- Hamilton’s 1940s urban area has intensified at a significantly faster rate than the city as a whole, driven mainly by growth in the commercial and industrial areas.
- Auckland’s 1940s urban area has intensified only marginally more than the city as a whole, driven by increased housing density and an expansion of the roading network.
- Wellington’s 1940s urban area has intensified moderately faster than the urban area as a whole, driven mainly by an increase in commercial/industrial areas (particularly Lower Hutt), followed by housing intensification.

## 5.2 Hamilton

### 5.2.1 Urban area

The Hamilton urban area covered 14.7 $km^2$ in 1943, then more than tripled to 49.3 $km^2$ by 1979. By 2016 it was more than five times larger, at 75.2 $km^2$. Figure 13 shows the chosen urban boundaries for these three periods.

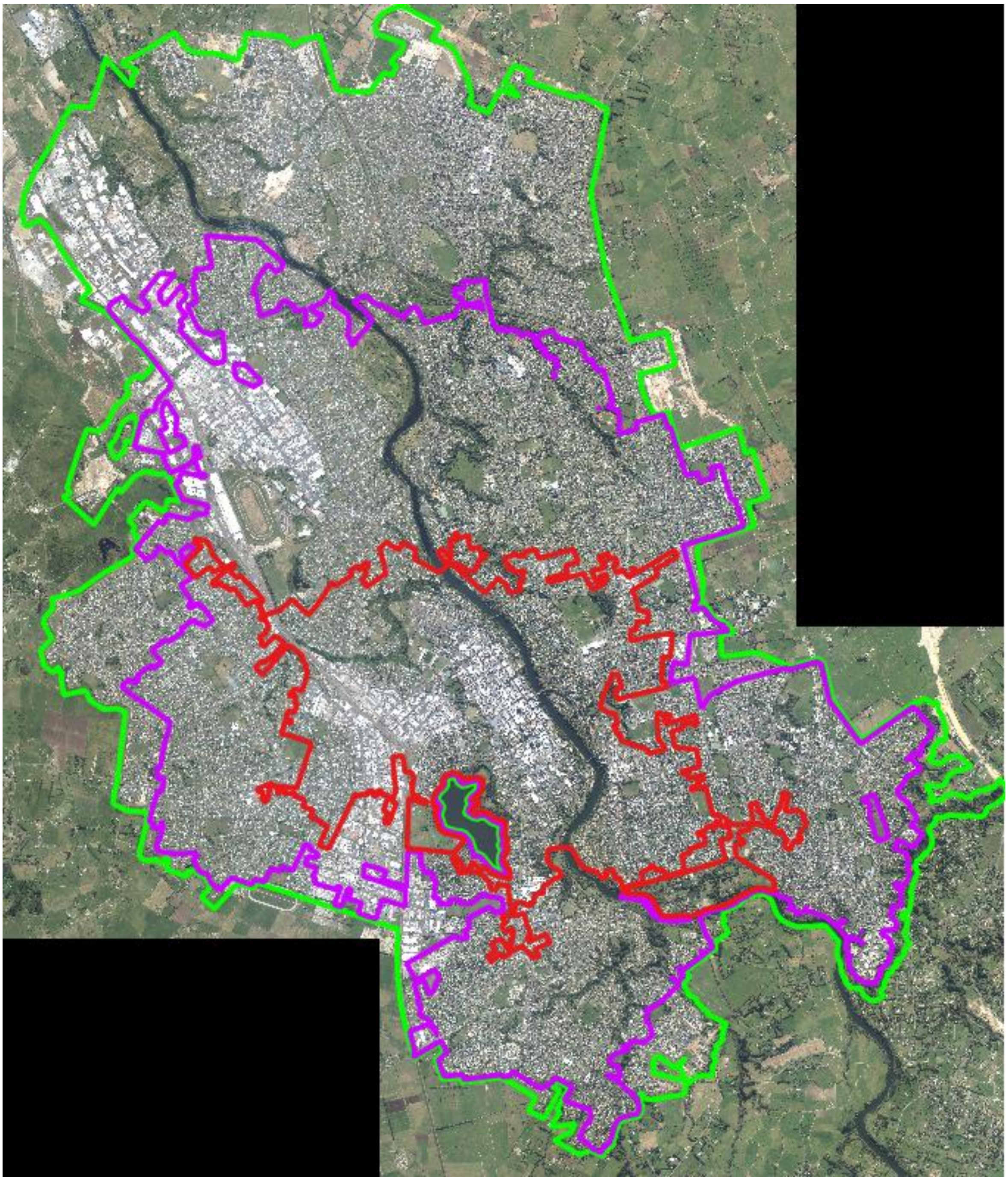

**Figure 13. Hamilton urban boundary in 1943 (red), 1979 (purple), and 2016 (green).**

### 5.2.2 Population density

The population of the Hamilton urban area has increased significantly, from around 16,000 in 1943 to 85,000 in 1979 and 138,000 in 2016 (five times and 8.6 times, respectively). For the period between 1940 and 1979 this is a significantly faster growth rate than that of the urban area itself, indicating the city has become more densely populated. Figure 14 shows population density by SAU for the three periods.

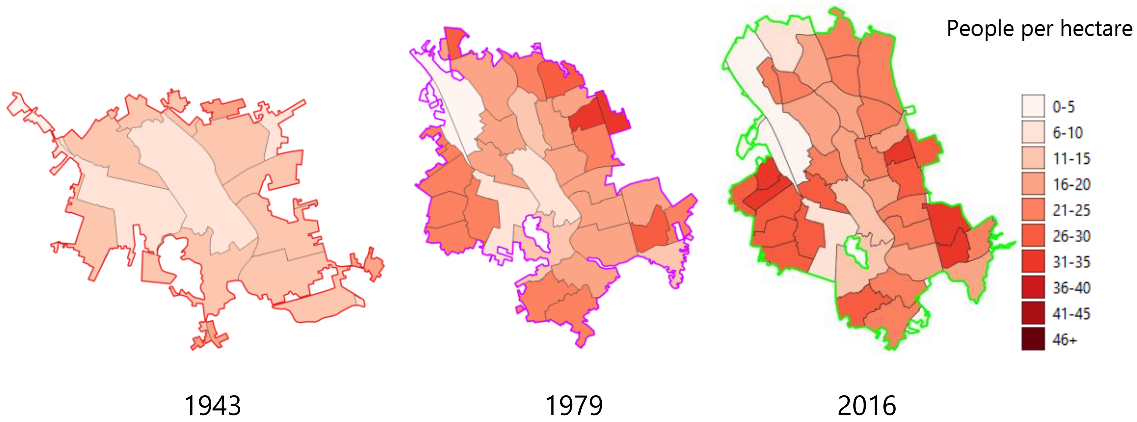


**Figure 14. Hamilton population density (people per hectare): 1943, 1979, and 2016 urban boundaries.**

These maps clearly show how parts of the city are becoming denser over time, with the highest density being in the newer areas as it grows out, and a more modest increase in density from infilling of older parts of the city. This correlates with our observations of the built form. The biggest change in density occurred between 1940 and 1979.

**Table 4. Hamilton population density**

| Period | City-wide density (people per hectare) |
|---|---|
| 1943 | 11 |
| 1979 | 17 |
| 2016 | 17 |

Table 4 summarises the overall density of the urban area. From these statistics we can see that the city underwent a significant increase in population density between 1943 and 1979, but then stopped. This matches our experience when trying to match historical imagery to the current built form: for 1979 there were large areas of the city that had similar building footprints to 2016, whereas for 1943 there were almost none that were substantially the same.

### 5.2.3 City composition and intensification

Figure 15 shows the breakdown of Hamilton city into its various functional units for the three periods.

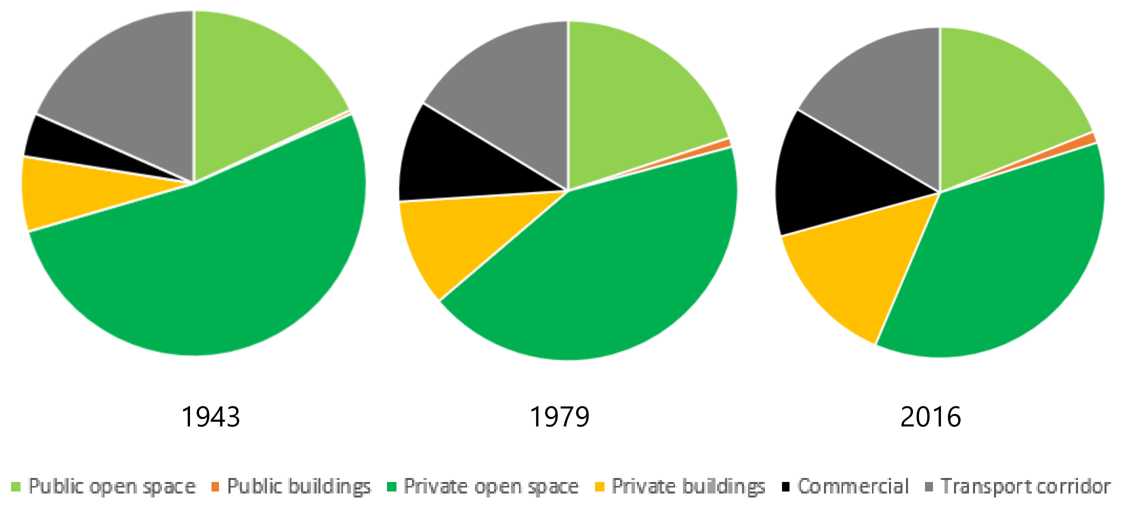


**Figure 15. Hamilton city composition: 1943, 1979 and 2016.**

The two biggest changes are the increased footprint of private dwellings, which more than doubles, and the growth of the commercial/industrial area, whose proportion approximately triples. The effect is more pronounced when considering just the area that was urban in 1943:

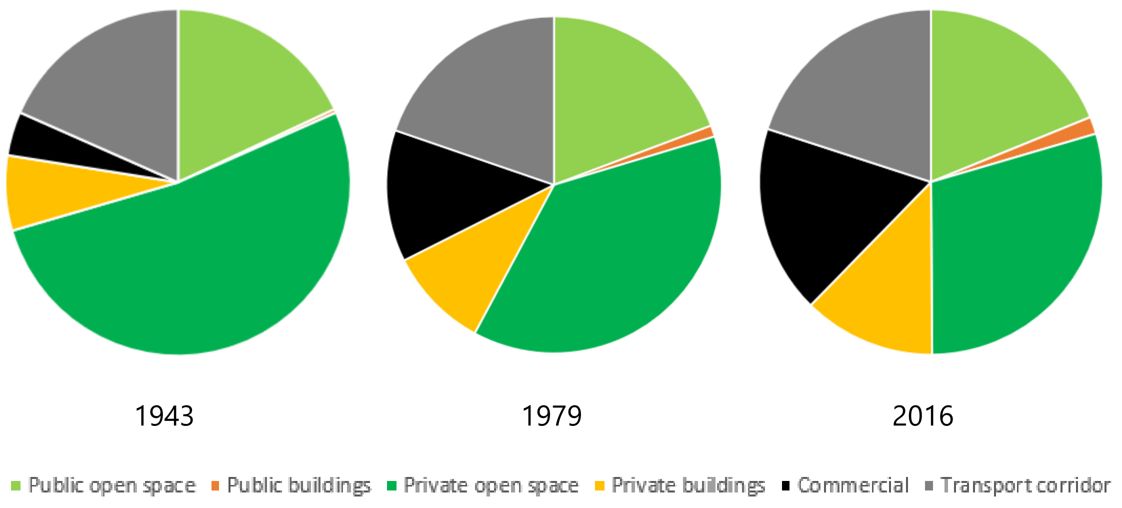


**Figure 16. Hamilton urban composition within 1943 boundary: 1943, 1979 and 2016.**

Figure 16 shows the breakdown of the urban space for the area contained within the 1943 boundary. While the picture is broadly the same, it is more pronounced, showing how this area has intensified at a greater rate when compared to the city overall. This is likely to be, in part, because new land is opened up as the city expands but takes time to be fully developed. In particular, the area taken up by commercial/industrial activity has grown substantially, resulting in a more pronounced reduction of *private* green space in 2016 to not much more than half what it was in 1943.

Hamilton has undergone substantial changes in built form since 1943. Figure 17 shows the building masks inferred for an area south of Claudelands showgrounds. This area has seen substantial infilling and change of the built structure between 1943 and 1979, with some further intensification between 1979 and 2016; this change is evident in the images and is captured well in the inferred building masks.

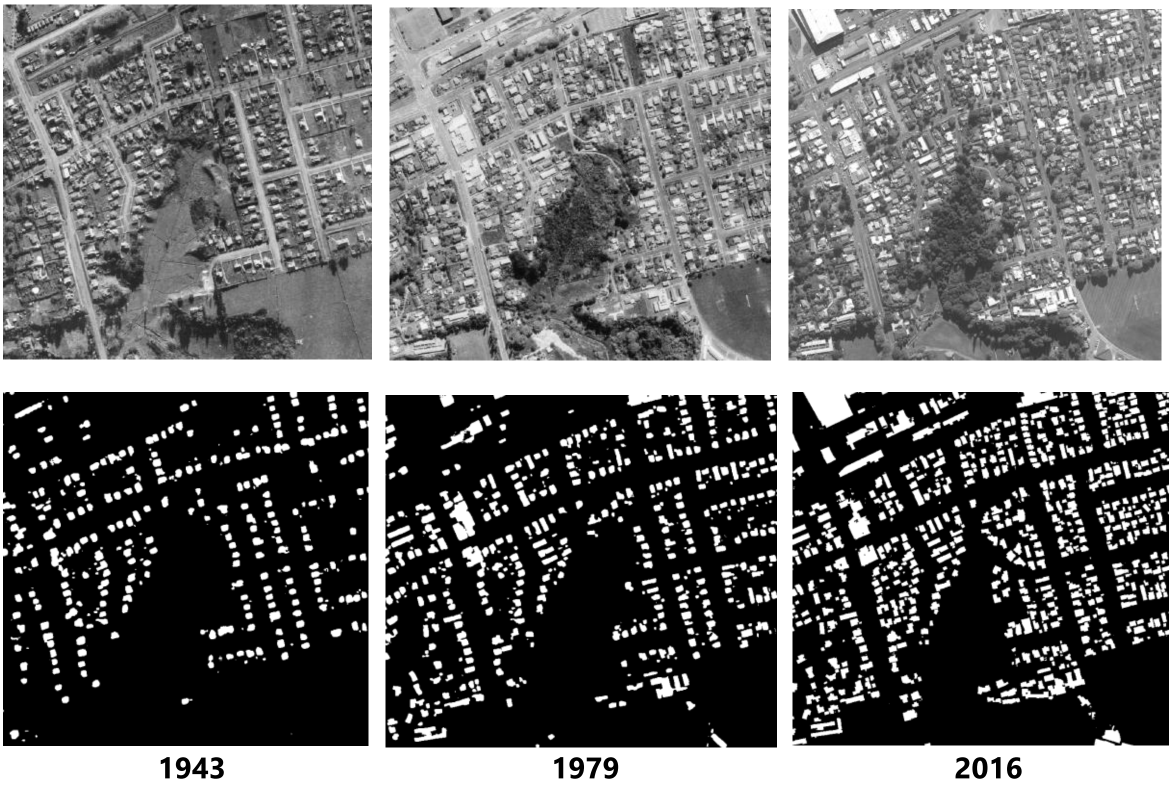


**Figure 17. Aerial images and building masks for Claudelands.**

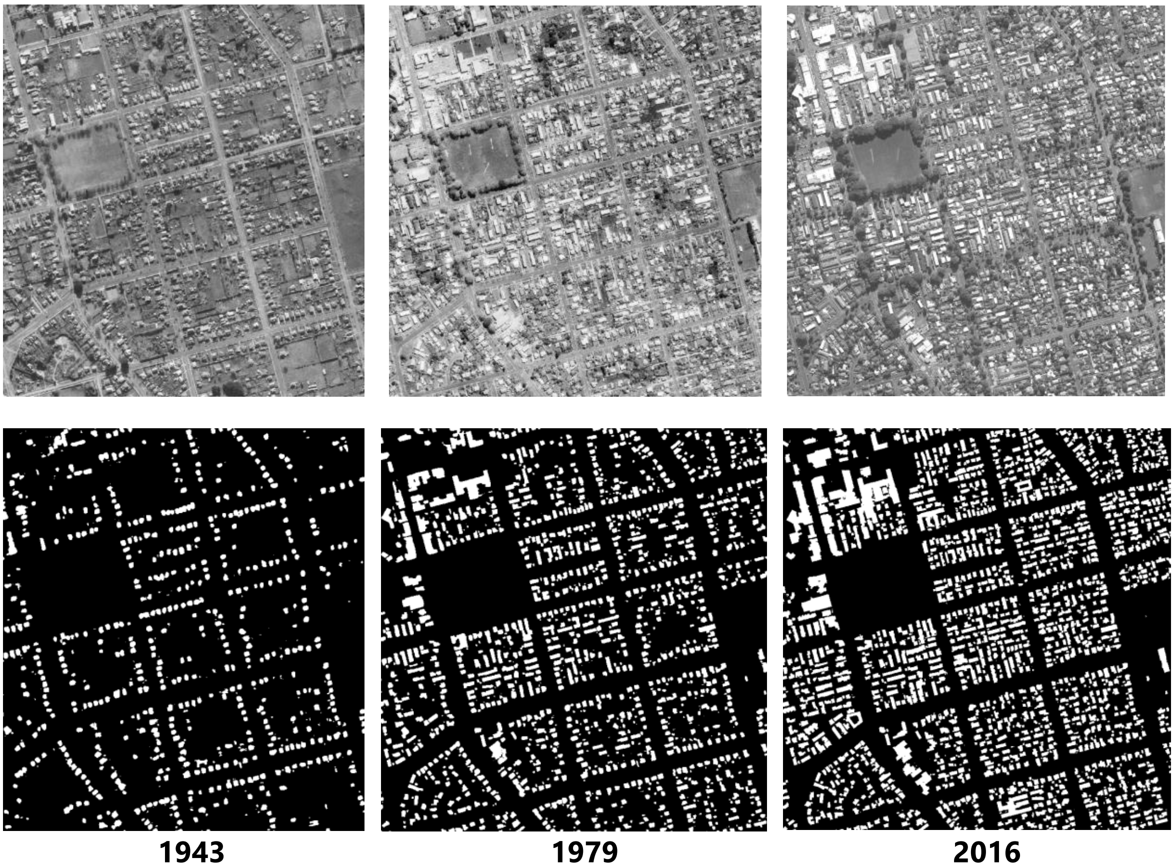


**Figure 18. Aerial images and building masks for Hamilton East.**

Figure 18 shows another three building masks, this time for Hamilton East, with aerial images for comparison. The substantial increase in density it captures is obvious from the images. A lesser amount of infilling from 1979 to 2016 is also evident.

The change in density over time is still evident today. The three images and building masks in Figure 19 are from an area in the historical precinct, a new subdivision in 1943, and a new subdivision in 2016, and the change in building density is evident in the building masks. The 1943 new subdivision has a noticeably lower density than the older inner-city precinct, while the new Rotokauri subdivision on the Northeast boundary of the city in 2016 is the densest.

**Figure 19. Three samples of housing density in 2016: left: an area of historical inner city; centre: a subdivision established in the 1940s; right: a new subdivision established in the 2000s.**

### 5.2.4 Green space density by area

Figure 20 shows public green space density (public green space area divided by total area) by statistical area for the three periods. The proportional area of public green space remains largely static, but with some local effects, such as the addition of Waikato University. This initially results in a large local increase in public space density, but later reduces as the area becomes more built up (including the University itself adding buildings).

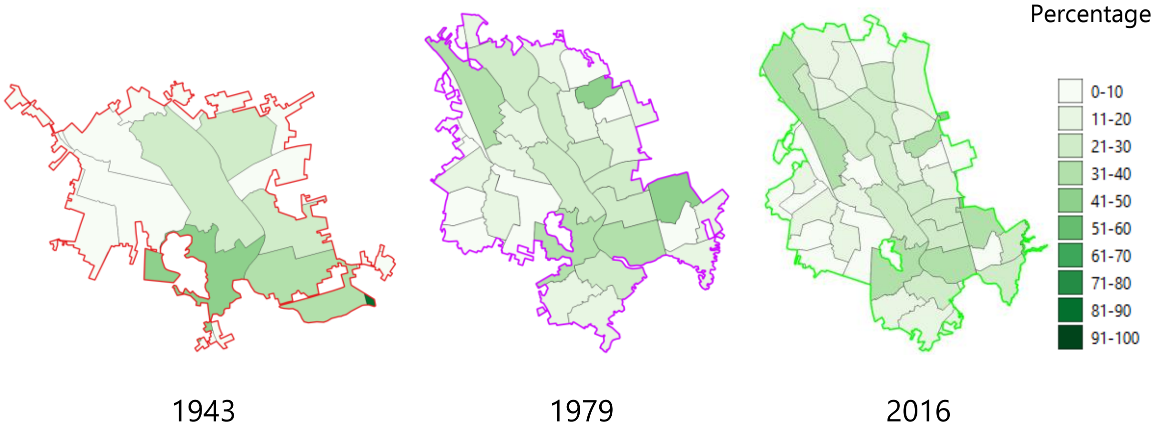


**Figure 20. Hamilton public green space density: 1943, 1979, and 2016.**

Figure 21 shows the corresponding proportion of private green space.

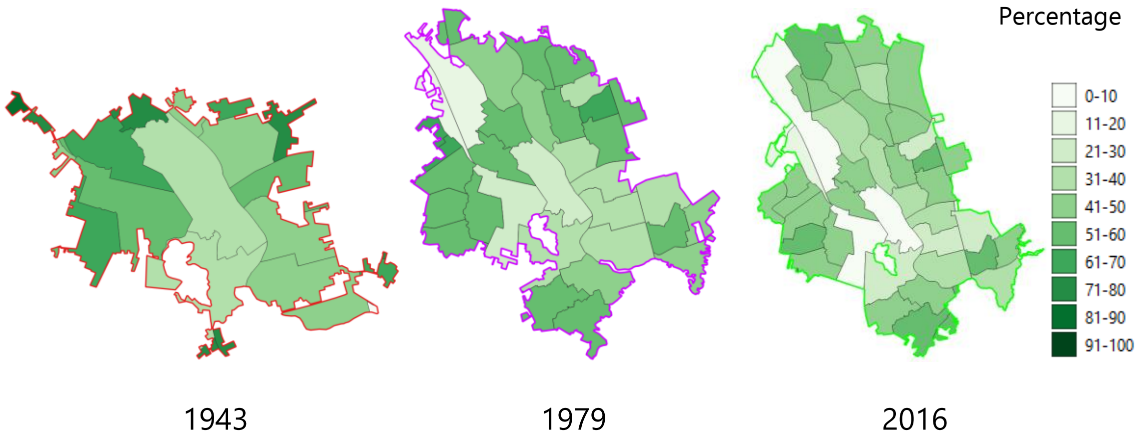


**Figure 21. Hamilton private green space density: 1943, 1979, and 2016.**

Overall green space is shown in Figure 22 and summarised in Table 5. Public green space provision in Hamilton has remained largely unchanged as a function of area, with new public green spaces continuing to be added as the city has grown. However, the average *private* green space has fallen 15 percentage points (a 30% decrease in the 1943 public green space area); this effect is relatively uniform across the city.

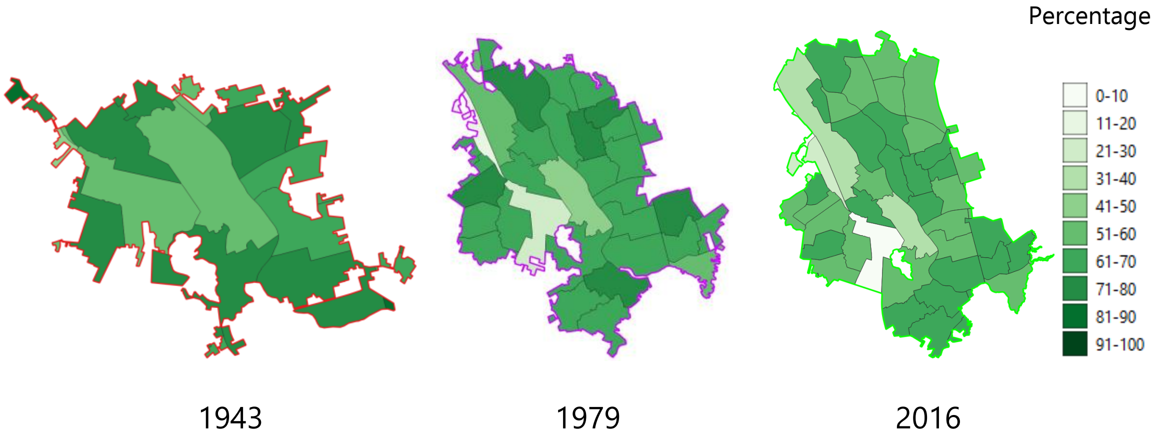


**Figure 22. Hamilton total green space density: 1943, 1979, and 2016.**

**Table 5. Hamilton summary of green space densities.**

| Period | Public % | Private % | Total % |
|---|---|---|---|
| 1943 | 17.5 | 50.5 | 68.1 |
| 1979 | 19.6 | 42.2 | 61.9 |
| 2016 | 18.6 | 35.6 | 54.2 |

These statistics suggest green space as a proportion of total urban area has fallen by around 14 percentage points (a loss of 20% of the 1943 total green space area).

### 5.2.5 Green space per person

Figure 23 shows the distribution of public, private, and total green space *per person* across the city for the three periods.

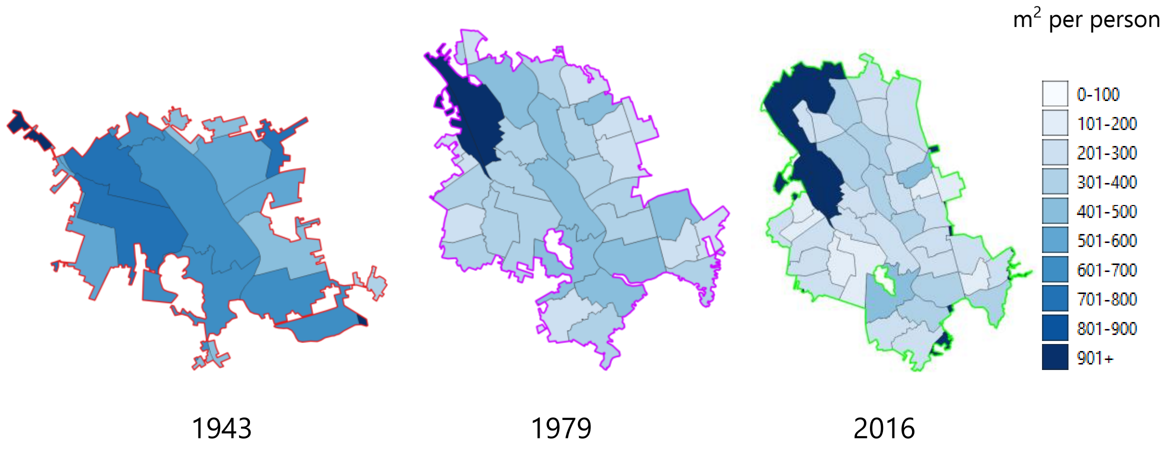


**Figure 23. Hamilton total green space ($m^2$) per person: 1943, 1979, and 2016.**

Table 6 summarises green space per person across the city. Once population is considered, the total green space available per person falls by around 53%, with public green space falling 36% and private green space falling almost 60%; this is consistent with the increased population and housing density observed. Note that the very high green space density areas (e.g. Te Rapa, Figure 23 top left, showing as deep navy blue) are anomalous areas where the population is very low (either newly added areas or because the statistical area covers mostly commercial space); overall the maps become less blue (i.e. less green space and/or more densely populated) as time goes by.

**Table 6. Hamilton green space per person**

| Period | Public $m^2$ per person | Private $m^2$ per person | Total $m^2$ per person |
|---|---|---|---|
| 1943 | 160 | 461 | 622 |
| 1979 | 114 | 245 | 359 |
| 2016 | 102 | 194 | 295 |

## 5.3 Auckland

### 5.3.1 Urban area

Auckland city covered 95 $km^2$ in 1940 (red boundary), quadrupled to 387 $km^2$ by 1980 (pink boundary), and then became more than five times larger by 2016 at 528 $km^2$ (green boundary). Figure 24 shows the chosen urban boundaries for the three periods.

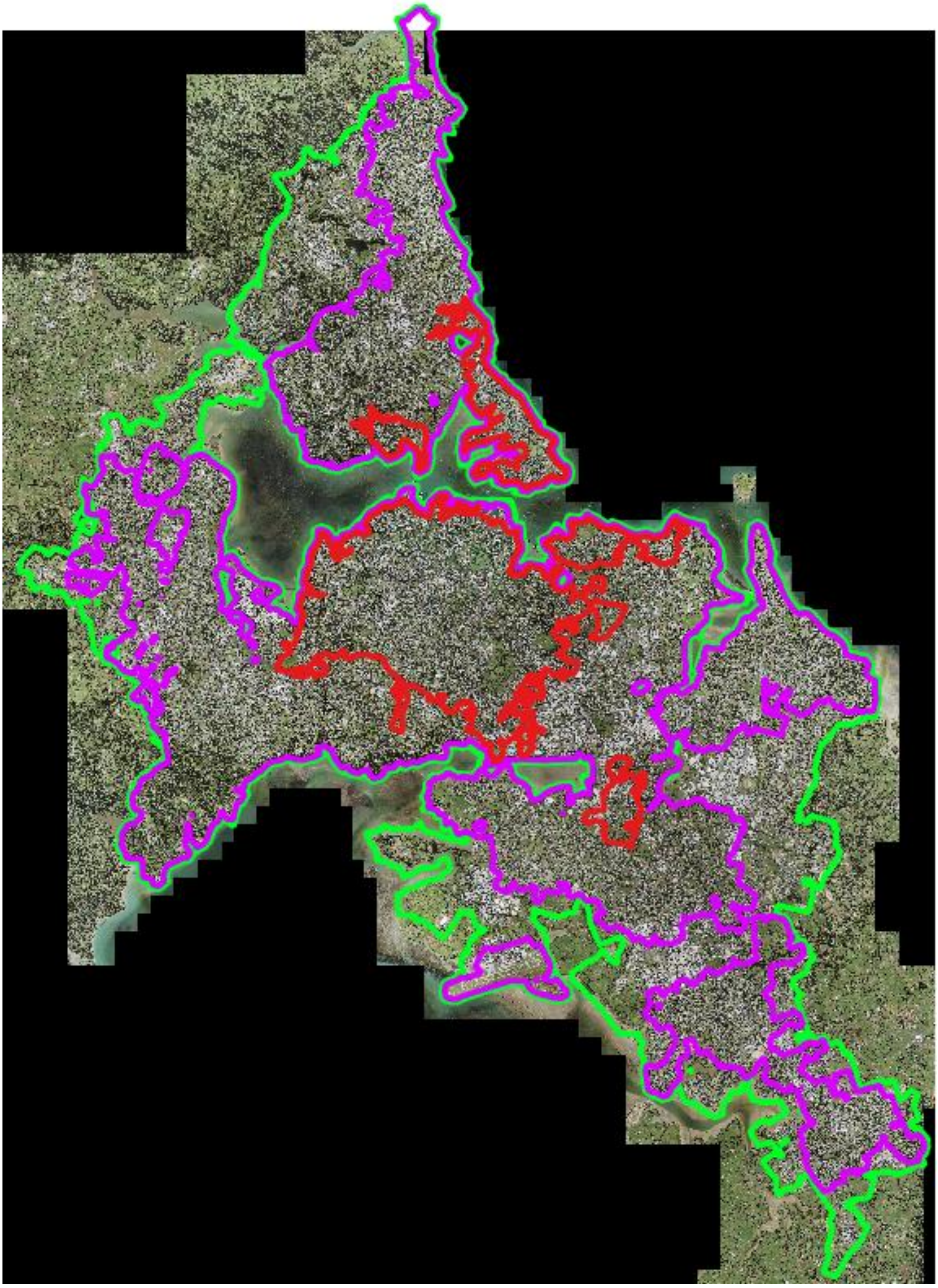

**Figure 24. Auckland urban boundary in 1940 (red), 1980 (pink), and 2016 (green).**

### 5.3.2 Population density

The population of Auckland has increased significantly from around 208,000 in 1940 to 727,000 in 1980 and 1.2 million in 2016, an increase of 5.8 times (vs Hamilton 8.6 times). In that time, parts of the city have also become more densely populated. Figure 25 shows population density by SAU for each period, taken from the nearest year for which detailed population statistics were available.

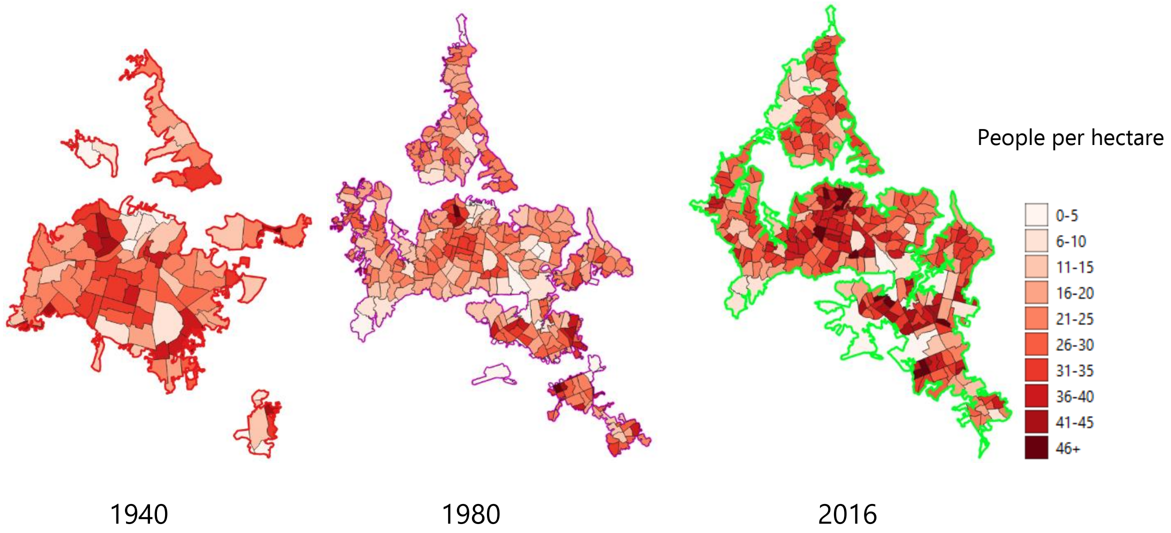


**Figure 25. Auckland population density: 1940, 1980, and 2016.**

These maps clearly show how parts of the city are becoming denser over time, with the highest density increase being in the central city (near the wharves), which has seen the population increase more than tenfold. However, this is offset by the addition of lower-density areas on the city's margins, particularly in Waitakere, and the addition of substantial public green space to the south (Manukau and Mangere). Overall, the population density (using these boundaries) has remained almost static (Table 7) and is significantly denser than Hamilton (23 versus 17 people per hectare).

**Table 7. Auckland population density over time**

| Period | City-wide density (people per hectare) |
|---|---|
| 1940 | 22 |
| 1980 | 19 |
| 2016 | 23 |

### 5.3.3 City composition and intensification

Figure 26 shows the breakdown of Auckland into its various functional units for the three periods.

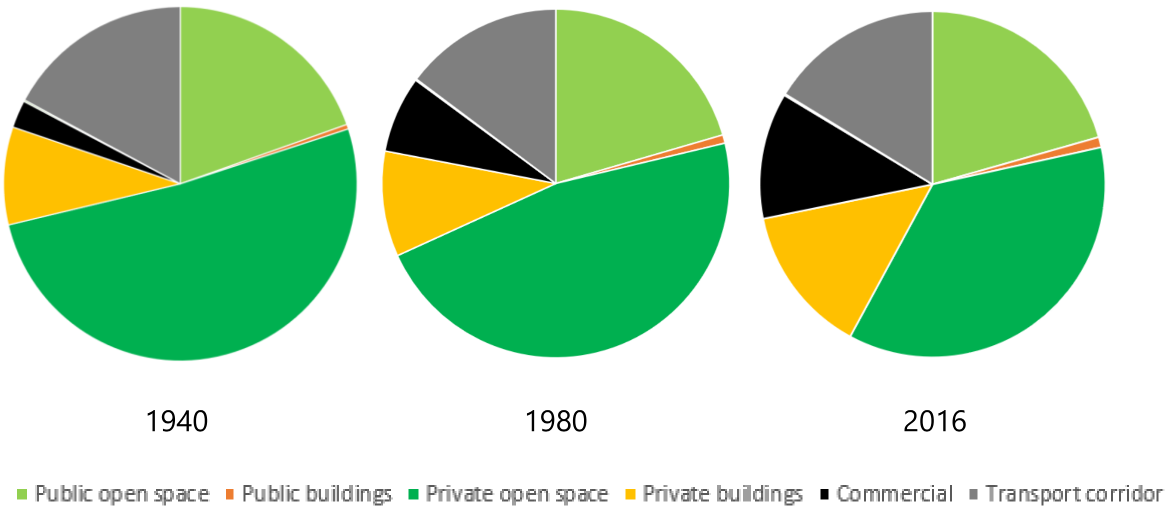


**Figure 26. Auckland city composition: 1940, 1980, and 2016.**

To see how the city's density is changing over time, Figure 27 shows Auckland's composition across the three periods for the area within the 1940 boundary.

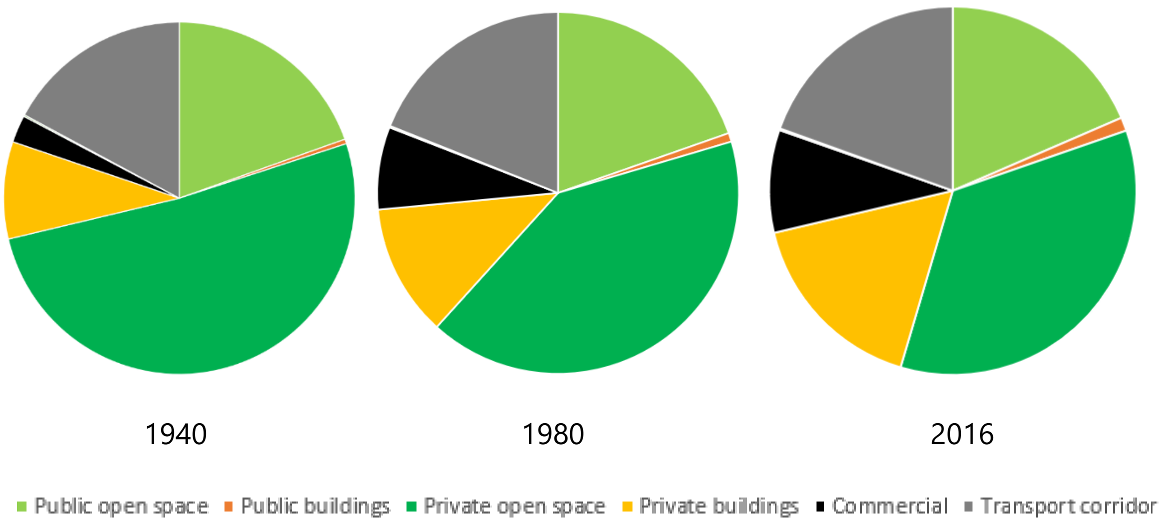


**Figure 27. Auckland composition – 1940 boundary: 1940, 1980, and 2016.**

The area within the 1940 boundary has intensified more than the city overall. Between 1940 and 1980 the main change is the increase in land used for commercial/industrial purposes, followed by the intensification of private buildings and the loss of private land to the transport corridor as motorways have been added or widened. By 2016 the area within the 1940s boundary has a higher private building footprint and roads take up a larger proportion of the land when compared to the city overall, but this older area has a lower commercial/industrial footprint. Overall, the older area has slightly less private green space, but the difference is small.

The residential built form has changed significantly over this period. In the period between 1940 and 1980 new greenfield developments were often relatively low density, particularly on the edge of the urban area. In contrast, between 1980 and 2016 new developments have tended towards townhouses, with significantly higher density and less green space. Figure 28 shows two examples: Pakuranga (pre-1980) and East Tamaki Heights (post-1980).

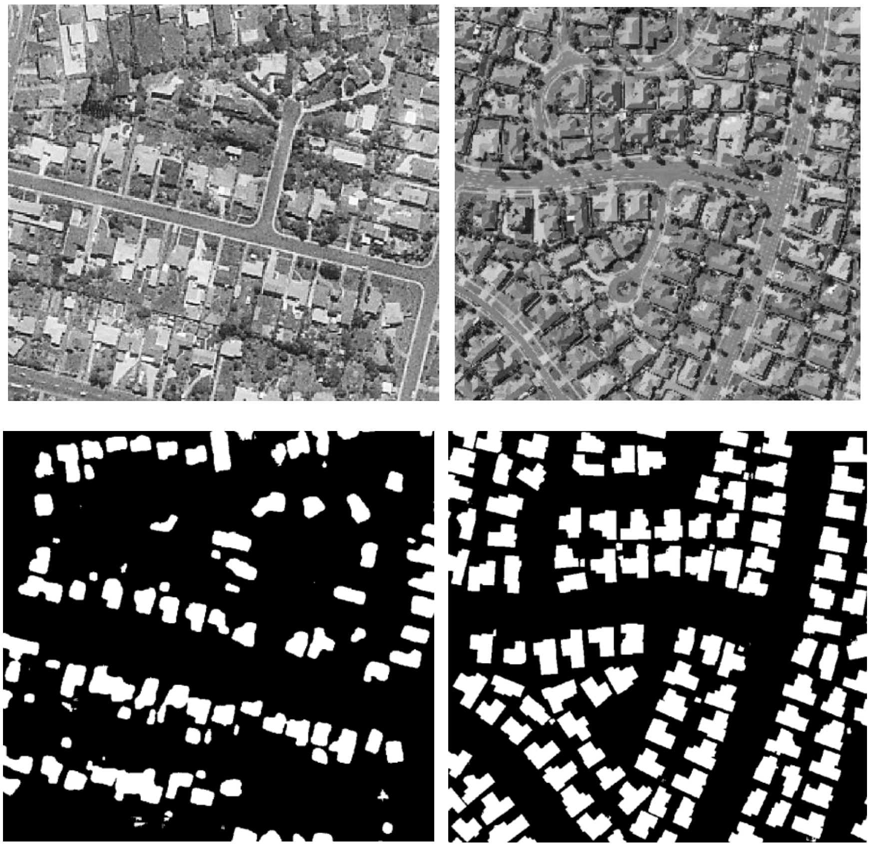

**Figure 28. Aerial images and building masks for Pakuranga (1980 mask) and East Tamaki Heights (2016 mask).**

### 5.3.4 Green space density by area

Figure 29 shows public green space density by area for the three periods for Auckland. Like Hamilton, the proportional area of public green space is largely unchanged, but there are some local effects, such as the addition of substantial public green space to the south (Manukau and Mangere).

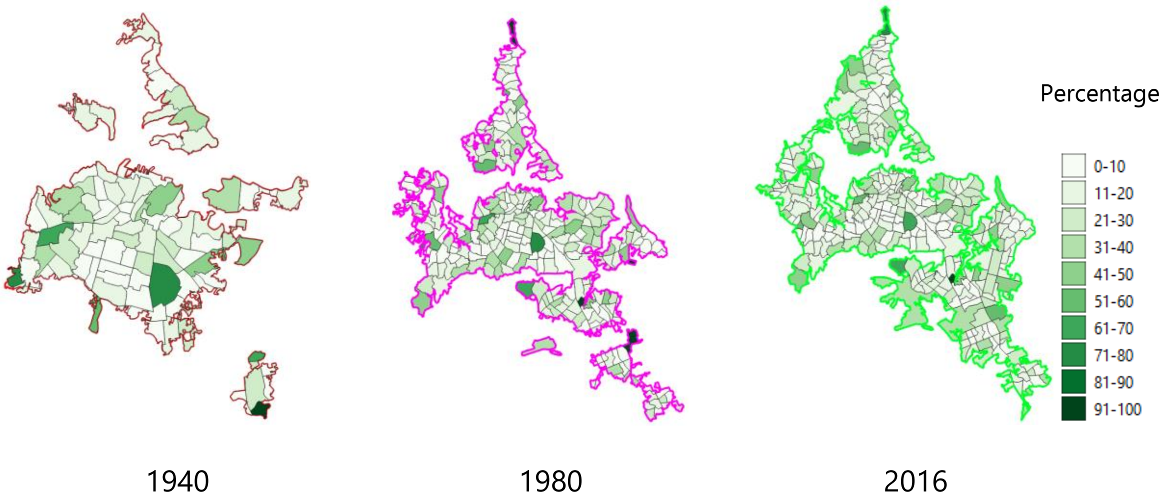


**Figure 29. Auckland public green space 1940, 1980 and 2016.**

Figure 30 shows the corresponding proportion of private green space.

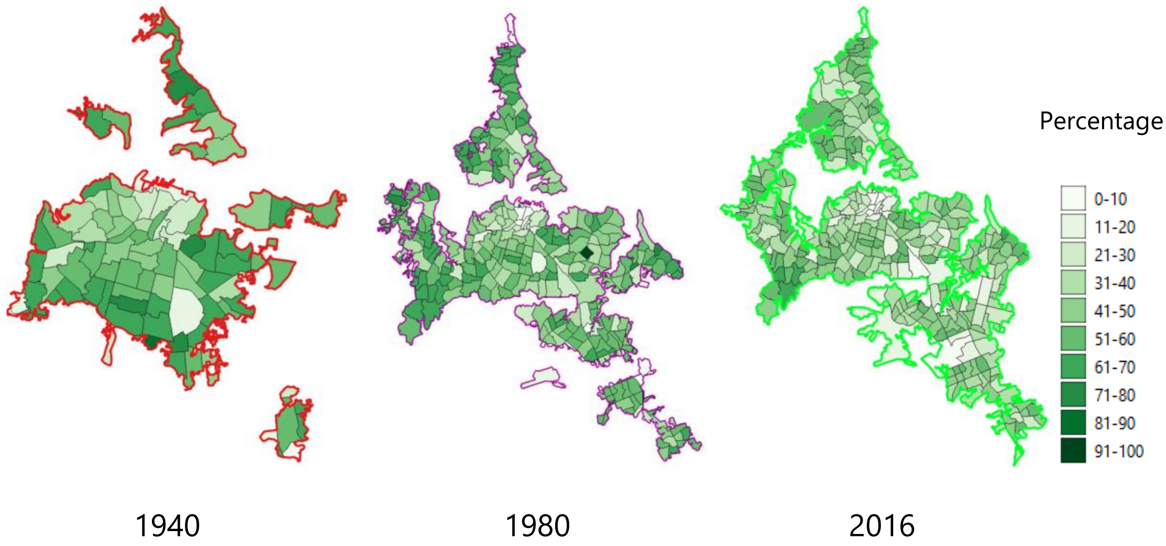


**Figure 30: Auckland private green space: 1940, 1980, and 2016.**

Overall green space is shown in Figure 31 and summarised in Table 8. Public green space provision in Auckland has remained largely unchanged as a function of area, with new public spaces continuing to be added as the city has grown. Overall, a slight increase is observed, mainly from the addition of public space around the margins, particularly around South Auckland (Mangere and Manukau). However, the average *private* space has fallen by around 15 percentage points (a 30% reduction of the 1940 private open space area); this effect is relatively uniform across the city. Total green space as a percentage of area has fallen by around 14 percentage points (a 20% reduction of the 1940 total green space area), the same as for Hamilton. Note that this does not take the increase in population density into account.

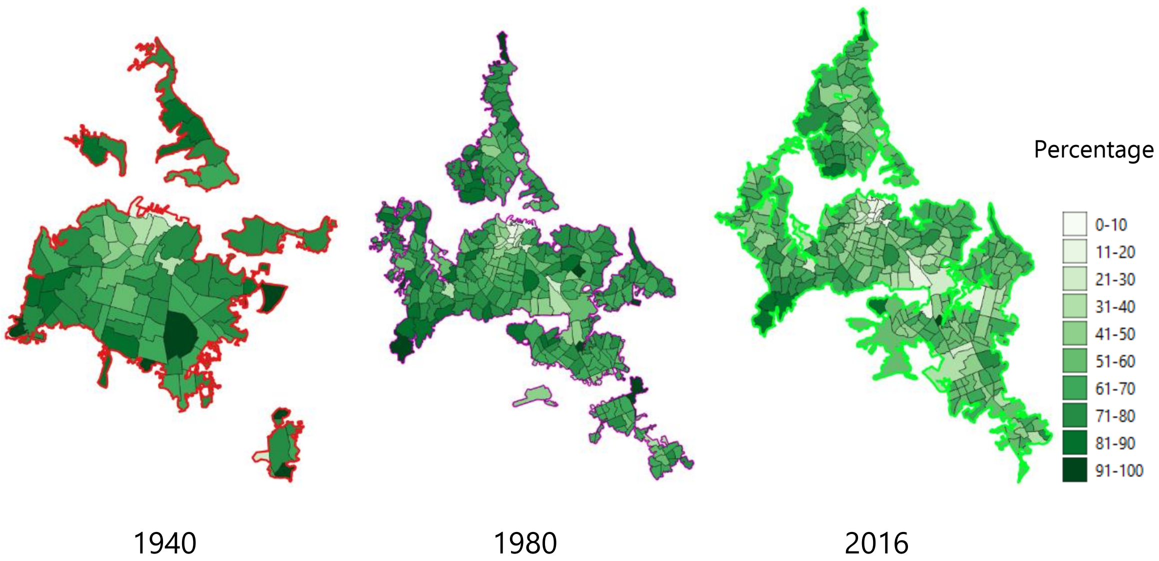


**Figure 31. Auckland total green space: 1940, 1980, and 2016.**

**Table 8. Summary of green space densities in Auckland**

| Period | Public % | Private % | Total % |
|---|---|---|---|
| 1940s | 19.5 | 51.5 | 70.9 |
| 1980s | 20.5 | 46.7 | 67.2 |
| 2016 | 20.6 | 36.2 | 56.8 |

Unlike Hamilton, where the decrease happened across the entire period from 1940 to 2016, a large proportion of the loss of (private) green space in Auckland occurred between 1980 and 2016. Following are the main drivers.

1 Auckland experienced significant infill housing over this time across most of the city, resulting in the built space roughly doubling.

2 While Auckland had substantial areas set aside for commercial purposes between 1940 and 1980, these areas were largely *unpaved* until sometime after 1980; hence, the commercial district was largely still contributing to green space. This may reflect a much higher proportion of mixed-use areas, where people both worked and lived in the same buildings. In contrast, Hamilton experienced a more deliberate development of purely commercial/industrial areas in the period between 1940 and 1980.

3 There has been a trend in new residential builds towards higher-density townhouses.

### 5.3.5 Green space per person

Figure 32 shows the distribution of total green space *per person* across the city for the three periods.

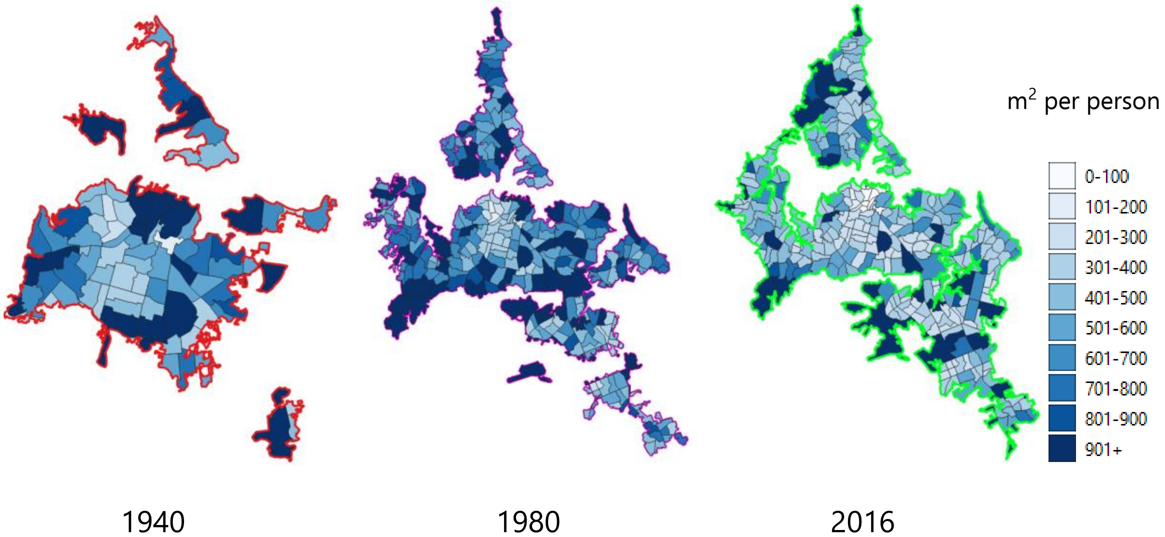


**Figure 32. Auckland total green space (m²) per person: 1940, 1980, and 2016.**

**Table 9. Auckland green space per person**

| Period | Public m²per person | Private m²per person | Total m²per person |
|---|---|---|---|
| 1940s | 89 | 234 | 323 |
| 1980s | 109 | 248 | 357 |
| 2016 | 89 | 157 | 247 |

Table 9 summarises green space per person across the city. Once population is accounted for, the total green space available per person *rises* by around 10% between the 1940s and 1980, but then falls by 31% between the 1980s and 2016. Overall, the loss of total green space per person is 23.5%, compared to Hamilton, which experienced a loss of over 50% of green space per person between the 1940s and 2016. However, by 2016 this green space in Auckland is concentrated in a few areas at the margins, with green space area per person in central Auckland falling substantially.  Figure 33 illustrates this point by comparing the total green space per person for the central city, as defined by the 1940 boundary.

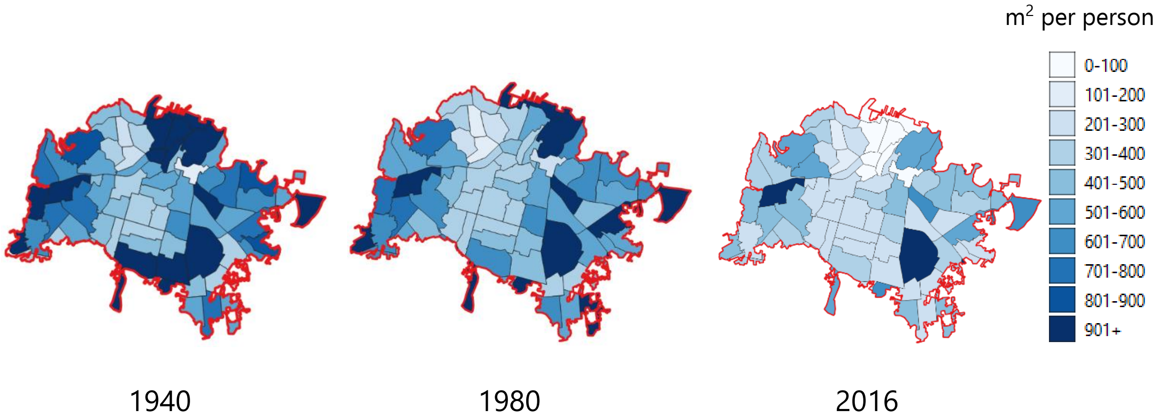


**Figure 33. Auckland central city green space ($m^2$) per person: 1940, 1980, and 2016.**

### 5.3.6 Case study: Mt Albert Central

Mt Albert Central has experienced a significant reduction in green space per person, largely due to an increase in population and the infill development required to accommodate it. Table 10 summarises population and green space for this SAU.

**Table 10. Mt Albert summary statistics**

| Measure | 1940 | 1980 | 2016 (vs 1940) |
|---|---|---|---|
| Population | 4,025 | 4,284 | 5,664 (+41%) |
| Public green space % | 21% | 20% | 19% (–10%) |
| Private green space % | 54% | 47% | 39% (–28%) |
| Total green space % | 75% | 67% | 59% (–21%) |
| Public green space $m^2$ per person | 99 | 92 | 66 (–33%) |
| Private green space $m^2$ per person | 261 | 212 | 134 (–49%) |
| Total green space $m^2$ per person | 360 | 305 | 200 (–44%) |

Figure 34 shows the building masks for Mt Albert for 1940, 1980, and 2016, as well as cropped aerial images and building masks for the centre of the SAU. These confirm that Mt Albert's built form has experienced significant infill development. The larger share of this happened between 1980 and 2016, during which time more than a quarter of the private green space was lost, resulting in the private green space *per person* decreasing by almost half.

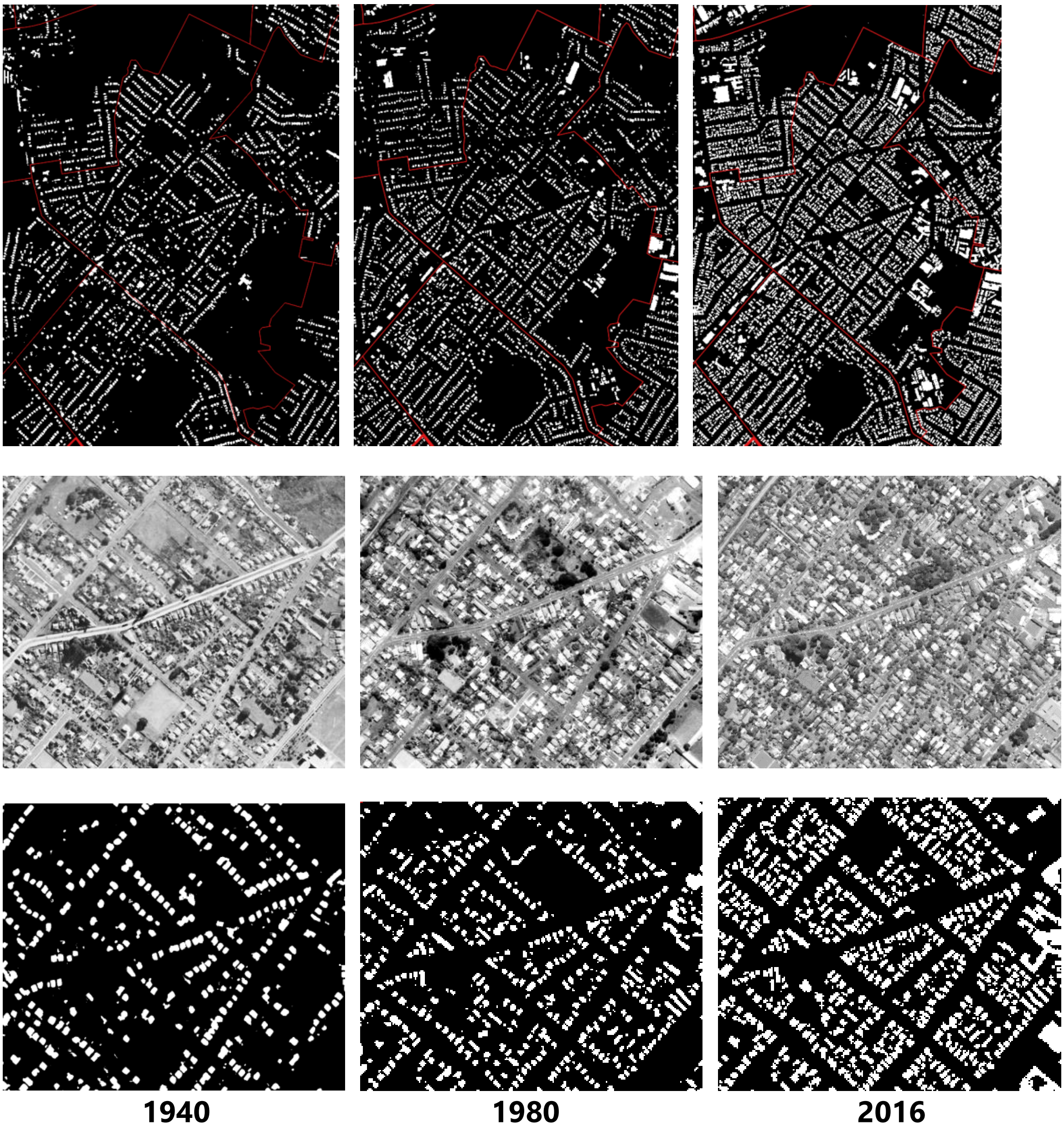


**Figure 34. Building masks and aerial images for Mt Albert 1940, 1980, and 2016.**
**Top row: building masks; middle row: aerial images for an enlargement from the centre of the suburb; bottom row: the corresponding building masks.**

## 5.4 Wellington

### 5.4.1 Urban area

Wellington has grown from 76 km$^2$ in 1940, almost tripling to 216 km$^2$ in 1980, and at almost 250 km$^2$ is more than three times larger in 2016. This is a significantly lower area growth rate than that of Hamilton or Auckland. Much of this change results from a large area of peri-urban green space being added to the Wellington urban areas: in 1941 Wellington had 11.8 km$^2$ of peri-urban green space (mostly around Lower Hutt), compared to 49 km$^2$ in 1980 and 57 km$^2$ in 2016. Figure 35 shows the chosen urban boundaries for the three periods.

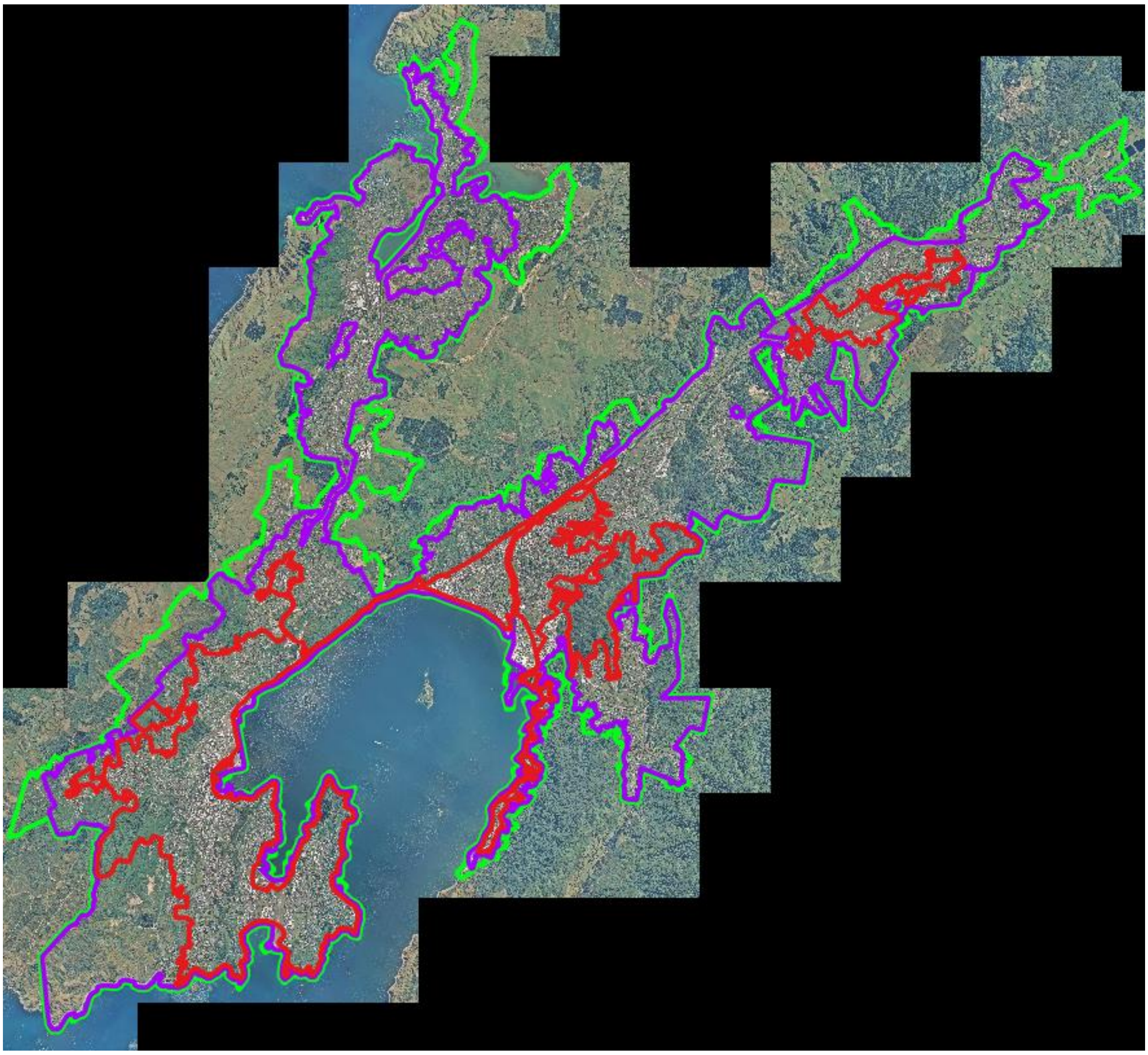

**Figure 35. Wellington urban boundary in 1941 (red), 1980 (purple), and 2016 (green).**

### 5.4.2 Population density

The Wellington population has increased significantly from around 130,000 in 1940, growing 2.5 times to 316,000 in 1980, and to 360,000 in 2016, an overall increase of 2.8 times. This is substantially less than the growth over the same period of Auckland (5.8 times) and Hamilton (8.6 times). Figure 36 shows population density by SAU for each period, taken from the nearest year for which detailed population statistics were available.

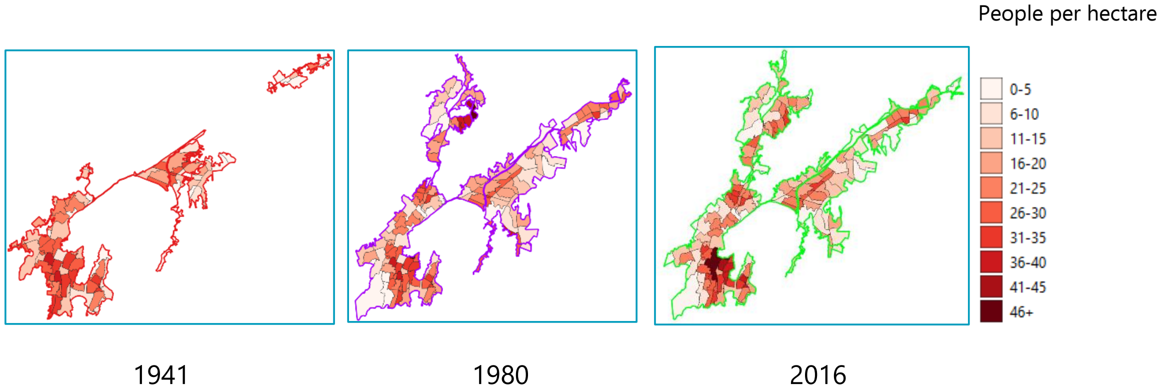


**Figure 36. Wellington population density (people per hectare): 1941, 1980, and 2016.**

These maps show how some parts of the city are becoming denser over time. The highest density increase is in the central city. This area has seen the population increase around tenfold since 1980, and the areas around it have more than doubled in density. However, this is offset by the addition of peri-urban reserves on the city's margins. Also, some parts of Porirua appear to have undergone a significant reduction in population density between 1980 and 2016. Overall, there is a small reduction in the population density (using these boundaries) due to the addition of peri-urban reserves. When these are excluded, the population remains almost static.

**Table 11. Wellington population density over time**

| Period | City-wide density (people per hectare) including peri-urban reserves | City-wide density (people per hectare) excluding peri-urban reserves |
|---|---|---|
| 1940 | 17 | 20 |
| 1980 | 14.5 | 18.9 |
| 2016 | 14.4 | 18.6 |

### 5.4.3 City composition and intensification

Figure 37 shows the breakdown of Wellington city (including peri-urban reserves) into its various functional units for the three periods.

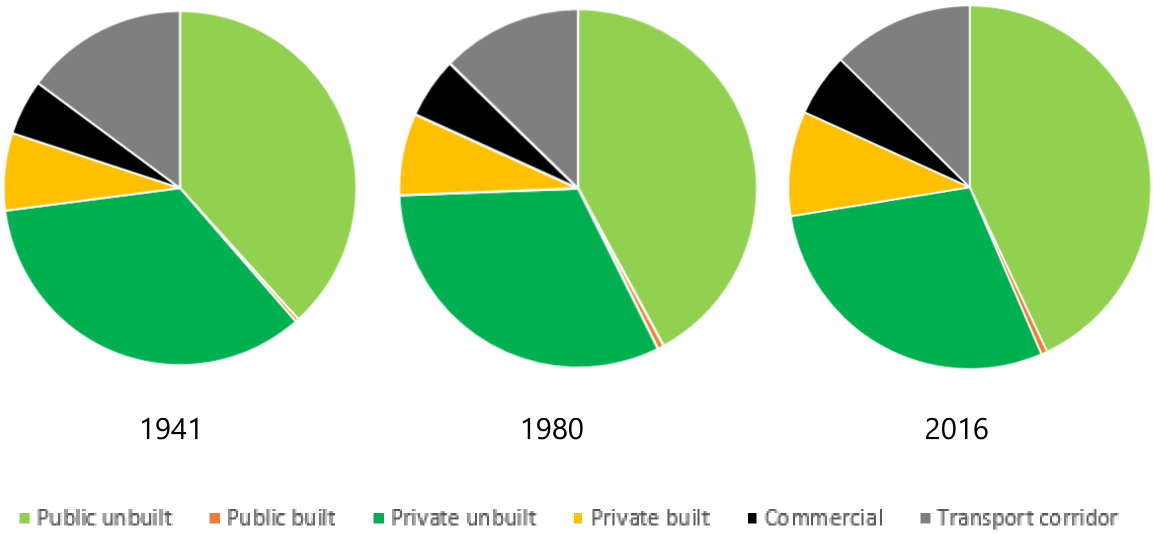


**Figure 37. Composition of Wellington: 1941, 1980, and 2016.**

Wellington's composition is relatively unchanged between 1941 and 1980. Then between 1980 and 2016 the proportion covered by private buildings grows, reducing the amount of private green space. This reduction is significantly less than seen in Hamilton and Auckland.

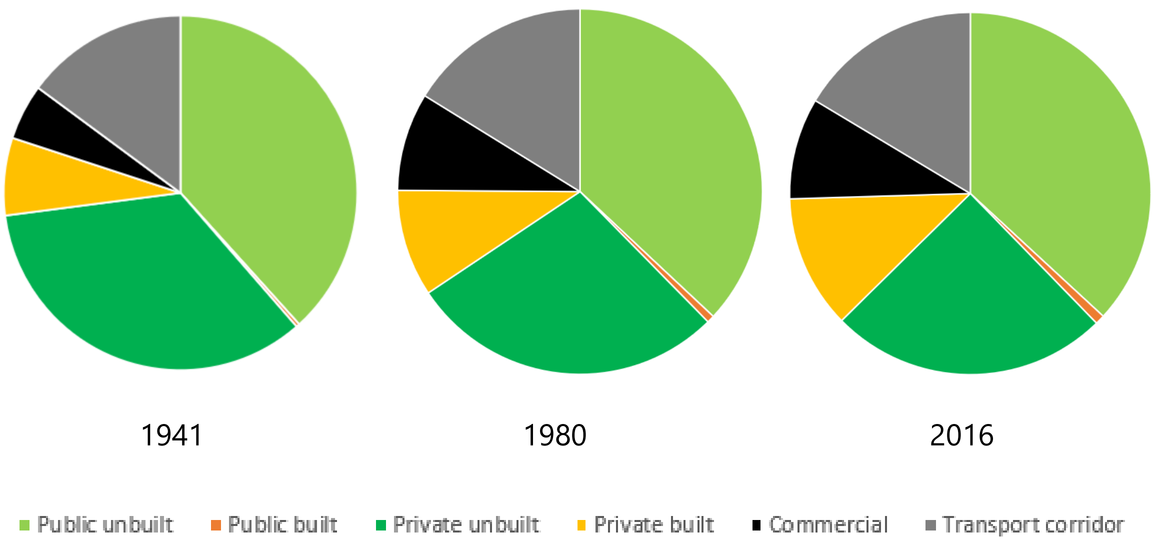


**Figure 38. Composition of Wellington – 1941 boundary: 1941, 1980, and 2016.**

In contrast, Figure 38 shows the changing composition of the city within the 1941 boundary. This clearly shows how the city has intensified: as well as the increase in density of private dwelling being more pronounced, the amount of space taken up by commercial/industrial activity almost doubles. The result is a significantly larger reduction in private green space. Industrialisation mainly takes place between 1941 and 1980, while the intensification of residential buildings is spread over the entire period.

Unlike Auckland and Hamilton, where greenfield residential developments have intensified significantly over the study period, in Wellington the effect is less pronounced. Often, the newer residential areas are *less* dense than for the earlier periods, presumably a consequence of the area's steep terrain: all land that can be easily built upon is efficiently utilised first, followed by steeper land at lower density. However, some new developments are beginning to follow the general trend of intensification (and corresponding loss of private green space) through larger houses and smaller sections. Figure 39 compares development patterns in Johnsonville: a new subdivision in 1941 was originally low density, but has since infilled, making it denser than a new development built around 1980. A post-1980 development nearby shows the trend towards larger houses.

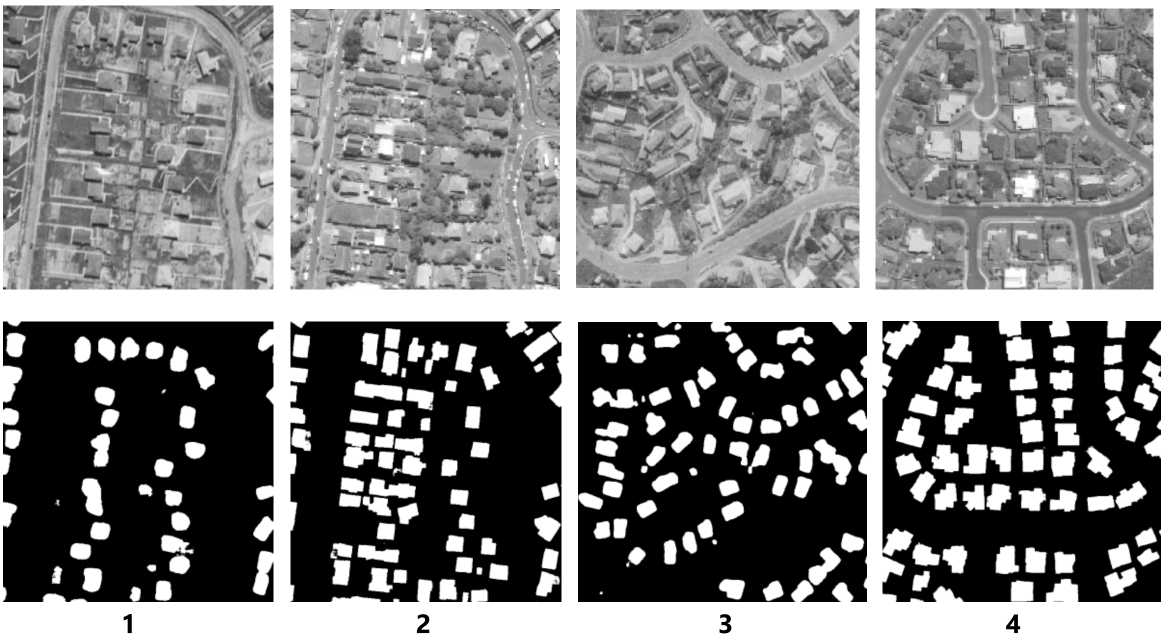


**Figure 39. Housing developments in Johnsonville: (1) a new development in 1941; (2) the same subdivision in 2016; (3) a new subdivision in 1980; (4) a new subdivision in 2016.**

### 5.4.4 Green space density by area

Figure 40 shows public green space density by area for the three periods for Wellington. The public green space density within the main urban areas has remained largely static. However, from 1980 onwards, large areas of public peri-urban green space were added, resulting in an order of magnitude increase in the green space available.

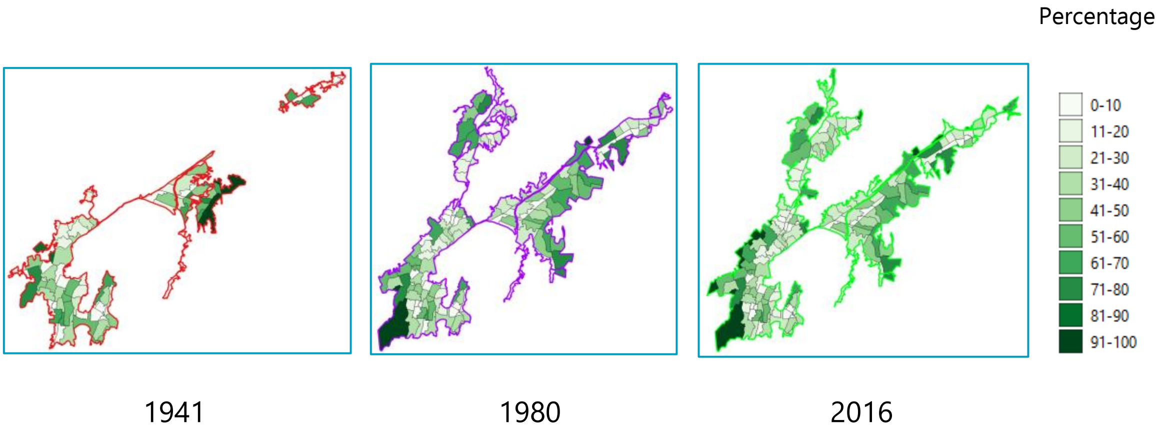


**Figure 40. Wellington public green space: 1941, 1980, and 2016.**

Figure 41 shows the corresponding proportion of private green space. Again, the private green space available in the main urban areas shows a modest reduction over time as the city becomes denser, but this effect is not as pronounced as in Hamilton or Auckland.

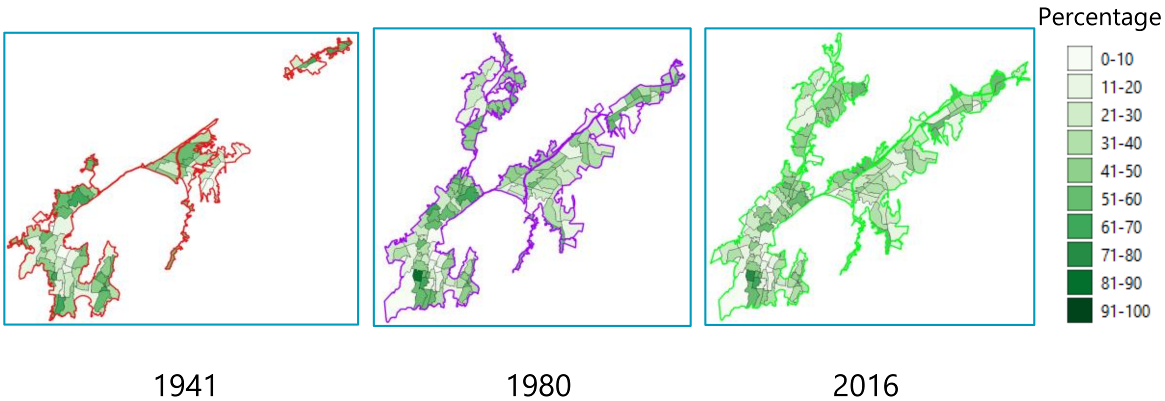


**Figure 41. Wellington private green space: 1941, 1980, and 2016.**

Figure 42 shows the total combined green space for the three periods. Within the main urban areas, the total green space has remained relatively unchanged, with the exception of the areas south and east of the airport, which have seen an expansion of development since 1941.

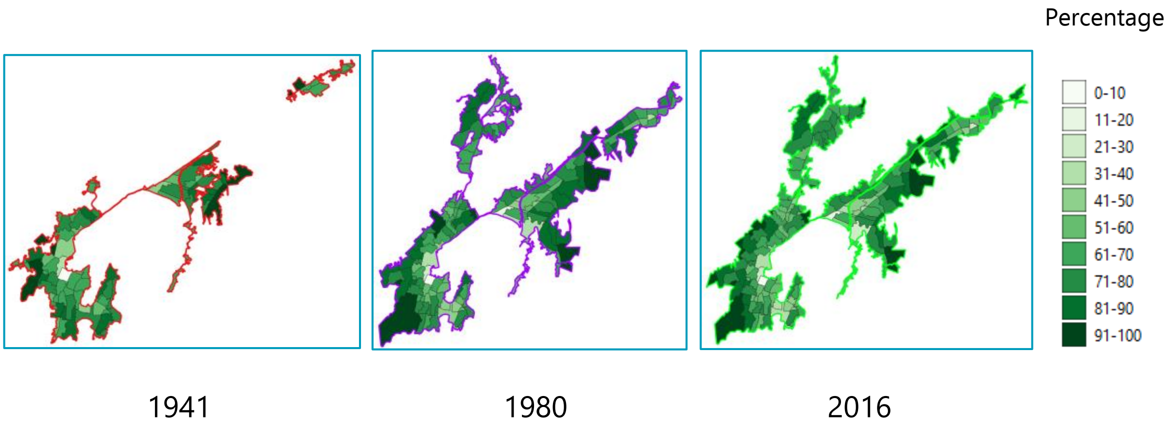


**Figure 42. Wellington total green space: 1941, 1980, and 2016.**

Table 12 summarises Wellington's green space. Total green space provision in Wellington has remained largely unchanged as a function of area (unlike Auckland and Hamilton, where total green space has fallen). This is because the addition of public green space around the urban margin has largely offset the reduction in private green space coverage. The proportion of the city that is public green space has *increased* by 4.8 percentage points (an increase of 12.5% of the 1941 public green space), while private green space has fallen by 5.3 percentage points (a 15.5% decrease of the 1940 private green space area).

**Table 12. summary of Wellington green space densities**

| Period | Public % | Private % | Total % |
|---|---|---|---|
| 1940s | 38.2 | 34.2 | 72.5 |
| 1980s | 42.1 | 31.7 | 73.7 |
| 2016 | 43.0 | 28.9 | 71.8 |

Like Hamilton, the loss of private green space has occurred across the entire period as the city has developed. In particular, Lower Hutt has industrialised, resulting in a significant loss of private green space from the previously residential areas. However, Wellington in 2016 is a significantly 'greener' city than Auckland or Hamilton, with almost 72% of the city's area being green space, compared to 57% and 54% for Auckland and Hamilton, respectively.

It should be noted that the Wellington area has changed markedly over this time, with the addition of Porirua and the considerable expansion of Upper Hutt, as well as the addition of peri-urban reserves. Table 13 shows the available green space when peri-urban reserves are excluded.

**Table 13. Wellington green space, excluding peri-urban reserves**

| Period | Public % | Private % | Total % |
|---|---|---|---|
| 1940s | 27.0 | 40.5 | 67.4 |
| 1980s | 25.1 | 41.0 | 66.1 |
| 2016 | 26.1 | 37.4 | 63.5 |

Wellington's proportion of green space is much closer to that of the other two cities once peri-urban green space is excluded: total green space has fallen by 3.9% (a reduction of 6% of the 1941 total green space area), with public green spaces falling only slightly and private green space falling by 3.5 percentage points (8% of the 1941 private green space area). This is similar to the pattern observed for both Auckland and Hamilton, but significantly less pronounced: for both these cities, public green space rose slightly, but private green space fell more substantially by around 15 percentage points (a 30% reduction of the 1940 private green space area).

### 5.4.5 Green space per person

Figure 43 shows the distribution of total green space *per person* across the city for the three periods.

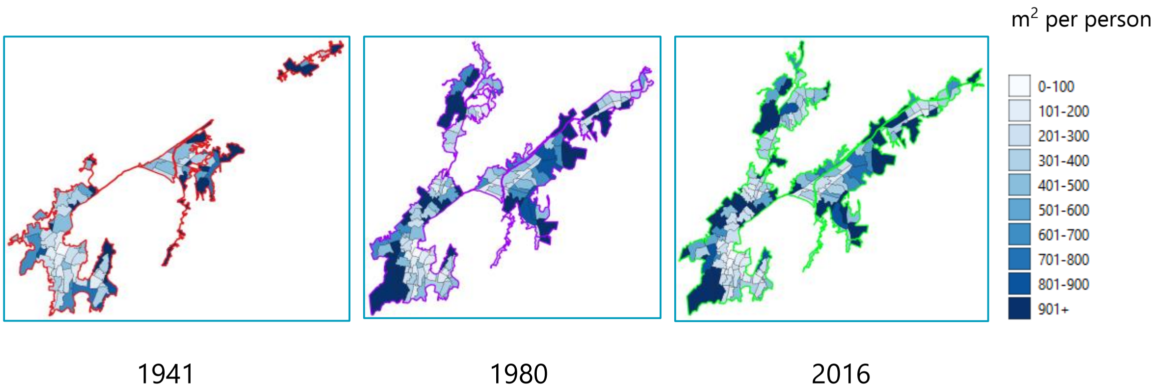


**Figure 43. Wellington total green space per person: 1940, 1980, and 2016.**

Table 14 summarises green space per person across the whole Wellington urban area. Once population is taken into account, the total green space available per person *rises* by 17.5% between the 1940s and 1980, then remains almost static. Overall, Wellington green space per person *increased* by 16.5%, compared to Hamilton and Auckland, which experienced a loss of green space per person of 23.5% and over 50%, respectively. Like Auckland, this green space is concentrated at the margins. However, Wellington's comparatively smaller size makes this space more accessible to urban dwellers on foot.

Figure 44 illustrates this point by comparing the total green space per person for the central city, as defined by the 1941 boundary. Between 1941 and 1980 the biggest changes occur from a loss of green space around the airport from its expansion, and increases in green space at the margins from the addition of new peri-urban reserves. Then, between 1980 and 2016 there is a modest increase in population density. This results in a small reduction in green space per person across the 1941 area.

**Table 14. Wellington green space per person, including peri-urban reserves**

| Period | Public $m^2$/person | Private $m^2$/person | Total $m^2$/person |
|---|---|---|---|
| 1940s | 226 | 202 | 428 |
| 1980s | 287 | 216 | 503 |
| 2016 | 299 | 201 | 499 |

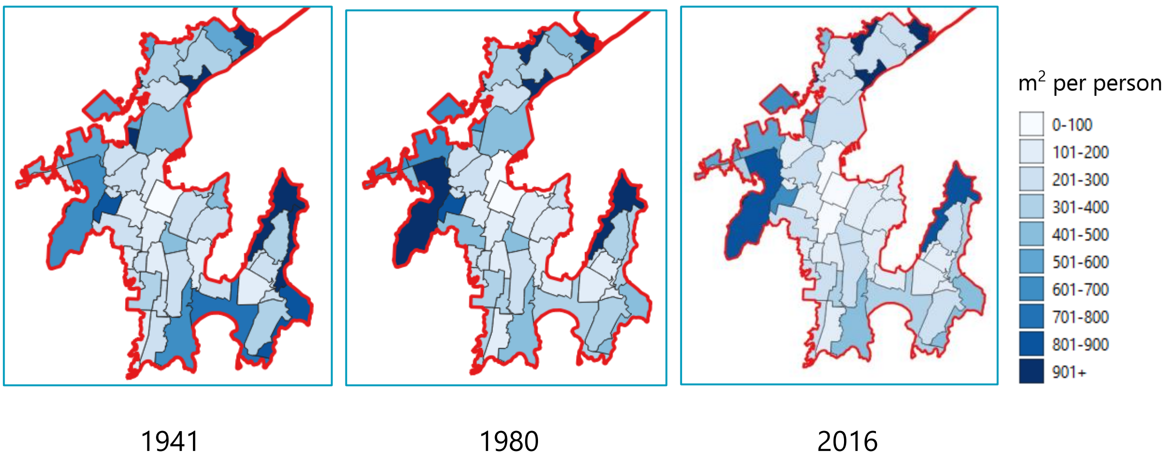


**Figure 44. Wellington central city green space per person: 1941, 1980, and 2016.**

Table 15 presents the same totals, but excluding the large peri-urban reserves. Once peri-urban reserves are excluded, Wellington's green space per person remains almost static, with a 4% increase in public green space, and private and total green space remaining essentially the same.

**Table 15. Wellington green space per person, excluding peri-urban reserves**

| Period | Public $m^2$/person | Private $m^2$/person | Total $m^2$/person |
|---|---|---|---|
| 1940s | 135 | 202 | 337 |
| 1980s | 133 | 216 | 349 |
| 2016 | 140 | 201 | 341 |

# 6 Conclusions

The three cities studied have experienced their own unique growth trajectories. At the start of the study (1940s), Hamilton was still a provincial town, while Auckland and Wellington were already cities. As a result, Hamilton industrialised at the same time as it experienced its main growth, while Auckland and Wellington grew more organically. While there are differences between the cities, all show a loss of green space, at least in the inner city, over this period.

All three cities have maintained a fairly consistent level of public green space proportion by area, with new reserves and other public amenities offsetting losses through growth, although this has been concentrated at the margins. In Auckland and Wellington the increase in public green space has kept pace with population growth, whereas in Hamilton the public green space available per person has reduced significantly.

However, the *private* green space proportion by area has reduced in all three cases, with the amount per person falling significantly for both Hamilton and Auckland. The main driver of loss of private green space is housing density, both the density of new subdivisions and infill housing in existing areas. Overall, population density has remained fairly static, with the exception of Hamilton during the period 1940–1980, when it became a city. However, there are strong localised effects, such as Mt Albert in Auckland, where a combination of a 41% population increase and a 28% loss of private green space led to an almost halving of private green space per person, and an overall green space loss per person of 44%.

All three cities have experienced significant intensification of the central city, as evidenced by the change in composition of the area occupied by the cities in the 1940s. In all three cases private green space has been lost to a mixture of housing intensification, industrialisation/commercialisation, and increased roading.

# 7 Recommendations

## 7.1 Study scope extensions

We have measured the change in public and private green space for three cities, across three time periods. The study could be extended in two ways to give a more complete picture.

- Repeat the study for the remaining Tier 1 cities (Tauranga and Christchurch). These two cities have factors that differentiate them from the three cities studied: Tauranga has had the highest rate of population growth of any New Zealand city in recent years, while Christchurch suffered the 2010 and 2011 major earthquakes, resulting in a complete rebuild of some parts of the city and a loss of urban development in others.
- Repeat for further time periods in the future as imagery becomes available; Wellington already has high-resolution (0.075 m) imagery available for 2021.

## 7.2 Methodology enhancements

This study has reported the patterns and trends of public and private green space in three New Zealand cities. Owing to the methodology adopted, some areas of grey space (e.g. driveways) were included in the analysis, and some areas of green space (e.g. roadside berms) excluded from it. As a result, there is a question as to how closely the results describe actual changes in urban green space. As well as the changes in land use described, other factors influence the amount of green space, including:

- the extent that private properties are paved – this becomes increasingly critical as section sizes reduce, because the proportion of a section covered in paving will increase
- the presence of green space in the roading corridor - this changes over time, with a significant proportion of roads in the 1940s being unsealed, versus more recent transport corridors including larger green berms; and streets may also be 'greened' by adding street trees and grass/planted berms and centre islands
- tree cover – while the ground available for green space may decrease, this might be offset through more and larger trees, such as for biodiversity services.

Regardless of whether green space can be accurately measured for the historical periods, it would be valuable to establish an alternative means of measuring it for the current period. The results from such an exercise could then be compared with those from the analysis undertaken here to provide an estimate of the error involved. Recent infrared imagery is available for all three cities, making it feasible to directly map green space with a high degree of accuracy.

Finally, it may be possible to infer a model of private green space versus housing density that could be used as a proxy to estimate green space for the historical periods.

## 7.3 Further analysis

Although this study focused on measuring change in urban green space, it has yielded considerably more data in the form of maps, which could be further analysed for other insights, particularly if the suggested enhancements to the methodology are carried out.

For example, the GIS layers could be analysed spatially to compare green space in New Zealand's cities to international best practice, such as the Urban Alliance 3-30-300 rule (3 trees visible from every dwelling; 30% tree canopy cover; 300 m maximum distance to a park or green space of 1 hectare or greater).[9]

Also, another area of increasing concern in urban areas is the growing extent of impervious surfaces, and this could be measured for the different land uses. If a satisfactory model can be produced that separates green space from grey, the rate of change could be measured using the historical photographs. Alternatively, samples could be taken from areas developed at different times (and relatively unchanged) to estimate the change.

# 8 Acknowledgements

We are grateful for the efforts of Andrew McCarthy, Shaun Killerby, Scott Kelly, and James Newman from the office of the Parliamentary Commissioner for the Environment for their research assistance and constructive feedback.

[9] https://iucnurbanalliance.org/promoting-health-and-wellbeing-through-urban-forests-introducing-the-3-30-300-rule/