An Assessment of Potential Impacts of Different Growth Scenarios on Auckland's Natural Environment

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Auckland Council
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Executive summary

Auckland's sustained population growth and its projected future growth, puts pressure on the natural environment. The concentration of people living in one particular area requires resources – land, water, energy, infrastructure and material flows. Economic efficiencies can be made through concentrating large numbers of people who live and work in urban areas, but resource flows also create waste streams and require the conversion of natural or rural land to built form.

Spatial policy and urban planning provide a bird's-eye view of future urban form. They provide a means of exploring scenarios and thinking about how the future might unfold, and how the urban footprint might evolve. The environmental effects of the future urban form are seldom represented in spatial plans. Nevertheless, there is agreement that urban growth impacts on air quality, water bodies and fertile soils. This has implications for human health and the health of terrestrial and marine ecosystems.

To understand the impact of different future urban forms on the natural environment this study compares the impact of three different urban form scenarios. By keeping total population and employment growth fixed out to the year 2046, this report explores the differences in impacts on the natural environment associated with differing urban development scenarios. A 'baseline scenario' urban form, based on up to date (as at December 2016) population and household growth projections used by Auckland Council, is developed. Two alternative growth distribution scenarios are subsequently developed; one where growth is concentrated into a smaller geographical area ('intensive' scenario) and another that distributes growth in a more dispersed and land-extensive form ('expansive' scenario).

A method to assess the potential impact of the three Auckland urban form scenarios on air quality, water bodies and fertile soil was developed. It is termed a 'value transfer' methodology, which is often used in other studies to estimate economic values of ecosystems and difficult to measure environmental effects. The value transfer method used the best available existing information from reliable completed New Zealand studies to measure and monetise each scenario. A value transfer method is appropriate to use in the context of urban form scenarios, as data is not always available on site-specific effects of future growth, yet data that has been previously observed in studies in a similar context, can be used to inform the likely effects.

The key results of the analysis show:

The intensive scenario could have the least effect on the environment, in terms of air quality and soil loss. In the absence of additional mitigation, the cost of damage for the expansive and baseline scenarios could be 100 per cent and 50 per cent higher, respectively, than the intensive scenario.

However, air emissions, particularly from transport and home heating, could have greater negative localised impacts under the intensive scenario. This reflects the relatively higher impact of emissions on human health in a dense built environment where more people are exposed and dispersion is poorer.

The impact on local air quality from home heating would be less under the intensive scenario relative to the other two scenarios, reflecting the removal of a greater number of solid fuel burners in the more intensive scenario.

Fertile soil loss in the expansive scenario is estimated to be 2.5 times higher than the intensive scenario, while the baseline scenario shows 1.7 times higher soil loss than the intensive scenario.

In terms of freshwater quality, further development in water catchments that are already partly developed (i.e. they contain some level of mitigation of negative effects) may be more cost-effective than attempting to mitigate negative effects on water quality in greenfield catchments with low urban influence, hence favouring the intensive scenario.

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Introduction

Auckland's sustained population growth and its projected future growth, puts pressure on the natural environment. The concentration of people living in one particular area requires resources – land, water, energy, infrastructure and material flows. Efficiencies can be made through concentrating large numbers of people who live and work in urban areas, but resource flows also create waste streams and require the conversion of natural or rural land to built form.

Spatial policy and urban planning provide a bird's-eye view of future urban form. They provide a means of exploring scenarios and thinking about how the future might unfold, and how the urban footprint might evolve. The environmental effects of the future urban form are seldom represented in spatial plans. Nevertheless, there is agreement that urban growth impacts on air quality, water bodies and fertile soils. This has implications for human health and the health of terrestrial and marine ecosystems.

Understanding the impact of different urban form scenarios on the natural environment is essential in order to manage the negative spill overs of urban development.

> "*Urban areas produce economic and social benefits that spring from the concentration of people and firms in urban areas. Yet, with increased concentration of people and activity comes increased pressure on the natural environment – notably through the creation of negative spillovers such as pollution, congestion and noise. In addition to obvious health impacts, a low-quality natural environment can discourage new businesses and skilled workers from establishing in urban areas. The challenge for government is to design and operate a system of urban planning that efficiently manages negative spillovers while not imposing costs that substantially undermine the economic and social benefits of urban living."* NZ Productivity Commission (2016), p.197.

The issue of the environmental and/or social costs of urban form is a topic of increasing interest to spatial policy advisors and related disciplines. However, there remains much scientific debate in this field because empirical analyses are rare. There are numerous studies on the effects of urban development and land use change on climate change, domestic air quality, freshwater, coastal environment and soils (e.g. particulate matter, Brochu et al., 2011; water quality, Tong and Chen, 2002; ozone concentration, Sicard et al., 2013) and ecosystem services[1] (e.g. landscape clustering and fragmentation, Ewing, 1997 and Pauleit et al., 2005; disturbances in the water balance, Samaniego and Barossy, 2006; soil compaction, EEA, 2006; air pollution and noise, Wiek and Binder, 2005; and increased risk of flooding, Bertoni, 2006). However, these studies employ a scientific methodology which cannot be suitably picked up and applied to practical spatial planning. In addition, the

[1] Nuissl et al. (2009) identify the main ecosystem services affected by land use change as: production of food, regulation of energy and matter flows, water supply, supply of recreational space, biodiversity or natural aesthetic values.

primary focus of these studies is not on the impact of land use change or intensive versus expansive forms of development, but rather the evaluation of urban development processes in general (Nuissl et al., 2009).

As an example of the limited studies comparing several development scenarios, Camagni et al. (2002) studied the specific environmental costs resulting from different patterns of urban expansion in the metropolitan area of Milan. Focusing in particular on land consumption and mobility generation, they defined different typologies of urban expansion. An impact index weighting different journey-to-work trips with reference to mode and time length was developed at the city level. The statistical analysis showed that higher environmental impacts were associated with lower densities of development, more recent urbanisation processes and residential specialisation of the single municipalities.

More recently, Rothwell et al. (2015) used a life-cycle assessment (LCA) approach to analyse the environmental impacts of five land use scenarios. They used two housing development scenarios (greenfield and infill) and two types of food production (field and high-technology greenhouse lettuce production). These were used to compare the environmental impacts for different land use scenarios for transitional zones between urban and rural districts in a developed and growing city. The results clearly indicate that the infill housing scenarios have lower environmental impact than greenfield developments. The environmental impact categories of climate change, freshwater eutrophication, photochemical oxidant formation, particulate matter formation and human toxicity reduced by 25-43 per cent for infill scenarios in comparison to greenfield developments.

This report compares the impact of three different urban form scenarios on the natural environment. These scenarios have been defined to demonstrate three different geographical distributions of a fixed amount of total population and employment growth to 2046. The starting point for this assessment was a baseline scenario (scenario I9) that is the official, up to date growth dataset used by Auckland Council for planning purposes[2]. By using Scenario I9 as a base dataset, it was possible to keep certain growth assumptions consistent (i.e. consideration of the Unitary Plan future urban zones, FUZ). Two further scenarios were then developed. These two further scenarios were redistributions of the baseline scenario dataset to focus growth in a more intensive way and spread growth in a more expansive way.

The population data and the projections used are based on the 2013 census and the medium growth projection by Statistics New Zealand to 2046 (as at December 2016). Table 1 summarises the population distribution (number of households) of the three scenarios (namely: intensive, baseline and expansive) in 2046 compared to 2013.

[2] The growth dataset is based on December 2016 projections.

Table 1. Auckland Region Household Growth (2013-2046) by Unitary Plan zone category and Urban Form Scenario

Year	2013		2046					
Scenario			Baseline		Intensive		Expansive	
Urban	443,750	90%	693,805	79%	750,050	86%	635,359	73%
Rural	39,971	8%	65,088	7%	48,145	6%	85,299	10%
FUZ	11,374	2%	113,912	13%	74,610	9%	152,147	17%
Total	**495,096**	**100%**	**872,805**	**100%**	**872,805**	**100%**	**872,805**	**100%**

Figure 1 shows the difference between distribution of households in the intensive and expansive scenarios compared to the baseline scenario in 2046.

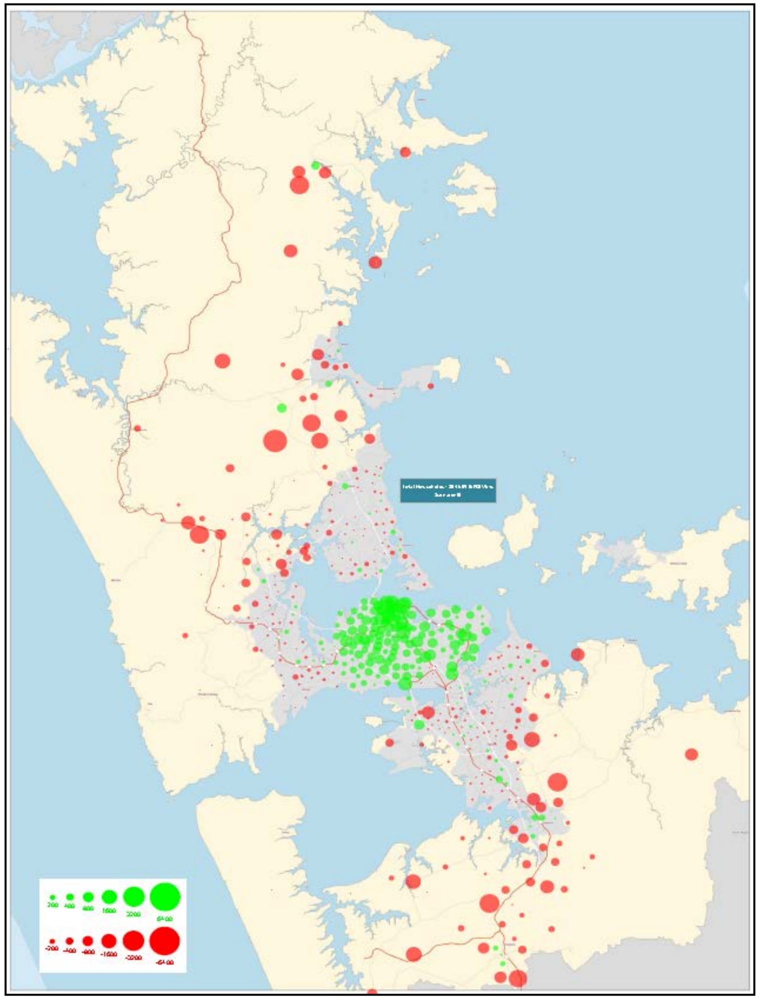
The aim of this assessment is to identify, measure and monetise the impact of each urban form scenario on the main natural environment components in Auckland – air quality, water bodies and fertile soil – where data is available. Consequently this is not a full assessment of the impact of the scenarios on Auckland's natural environment.

The report is structured as follows:

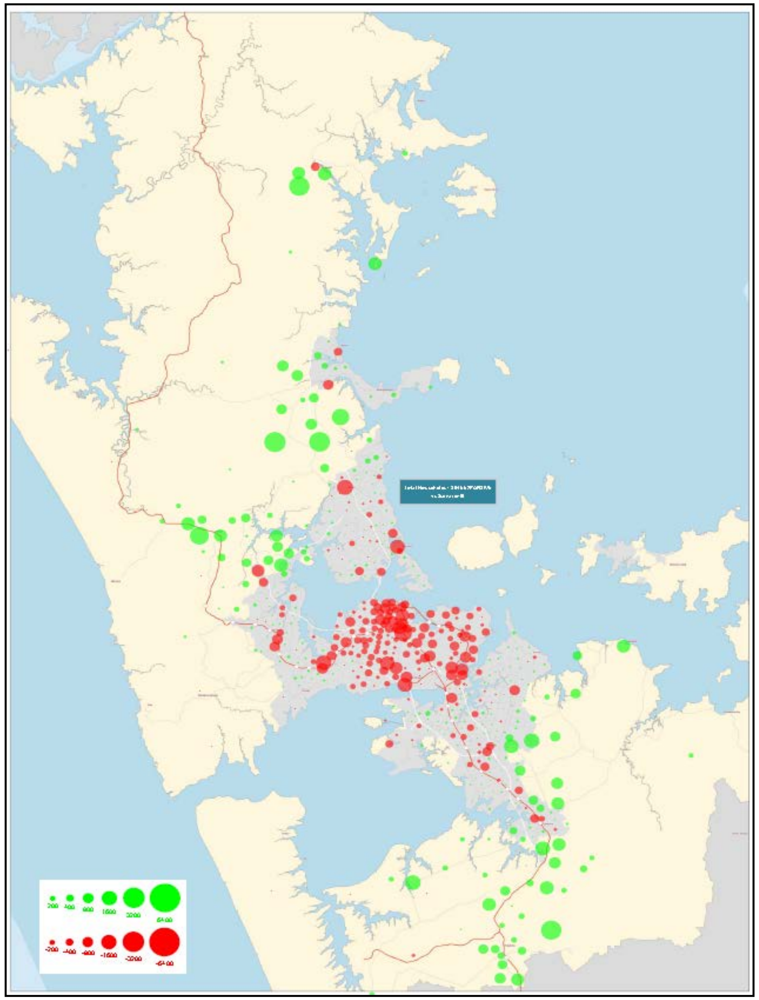
- The first section describes the general methodology and lists the data sources used in the assessment.
- The second section assesses the potential impact of each scenario on changes in local air quality and greenhouse gas emission.
- The potential impact of the urban form scenarios on Auckland's water bodies is discussed in the third section of the report.
- The potential impact of the expansive scenario on rural land and soils is the subject of the fourth section of the report; and
- The final section summarises the results.

Figure 1. Number of households (2046), intensive and expansive scenarios compared to baseline scenario

Intensive compared to baseline scenario



Expansive compared to baseline scenario



Note: Green and red bubbles show a higher or lower number of households in the area compared to the baseline scenario. The size of the bubble shows the magnitude of difference between scenarios.

1.0 Methodology and resources

The potential impact of the different urban form scenarios on air quality, water bodies and fertile soil in 2046 was identified, measured or monetised using available data sources, models and information taken from relevant studies. The methodologies used for each of the environmental components are summarised below:

- The impact of each scenario on air quality is monetised using the health cost of air pollution data from Watkiss (2002). The impact of changes in motor vehicle travel and home heating is estimated.
- The impact of land use development on water bodies is identified rather than quantified because it is not feasible to be measured and monetised. The nature of water is different from other environmental components as each catchment has specific characteristics that need to be assessed individually. Water degradation under each scenario is discussed using the result of Moores et al. (2016) that identifies various mitigation methods in relation to numerous development scenarios in Lucas Creek.
- The cost of agricultural land loss is measured under each scenario in 2046 and is based on the work of McDonald et al. (2009). The rural and future urban zone (FUZ) areas are the areas that would lose high class land due to new development. Figure 2 shows the rural and FUZ areas in the Auckland region by urban – rural classification for this assessment.

The sources used to inform the assessment are summarised in Table 2**.** They include relevant datasets, models and studies.

The rest of the report presents the detailed methodology and the results of assessing the potential impact of the development scenarios on air quality, water bodies and fertile soil.

Figure 2. Map of urban-rural classifications

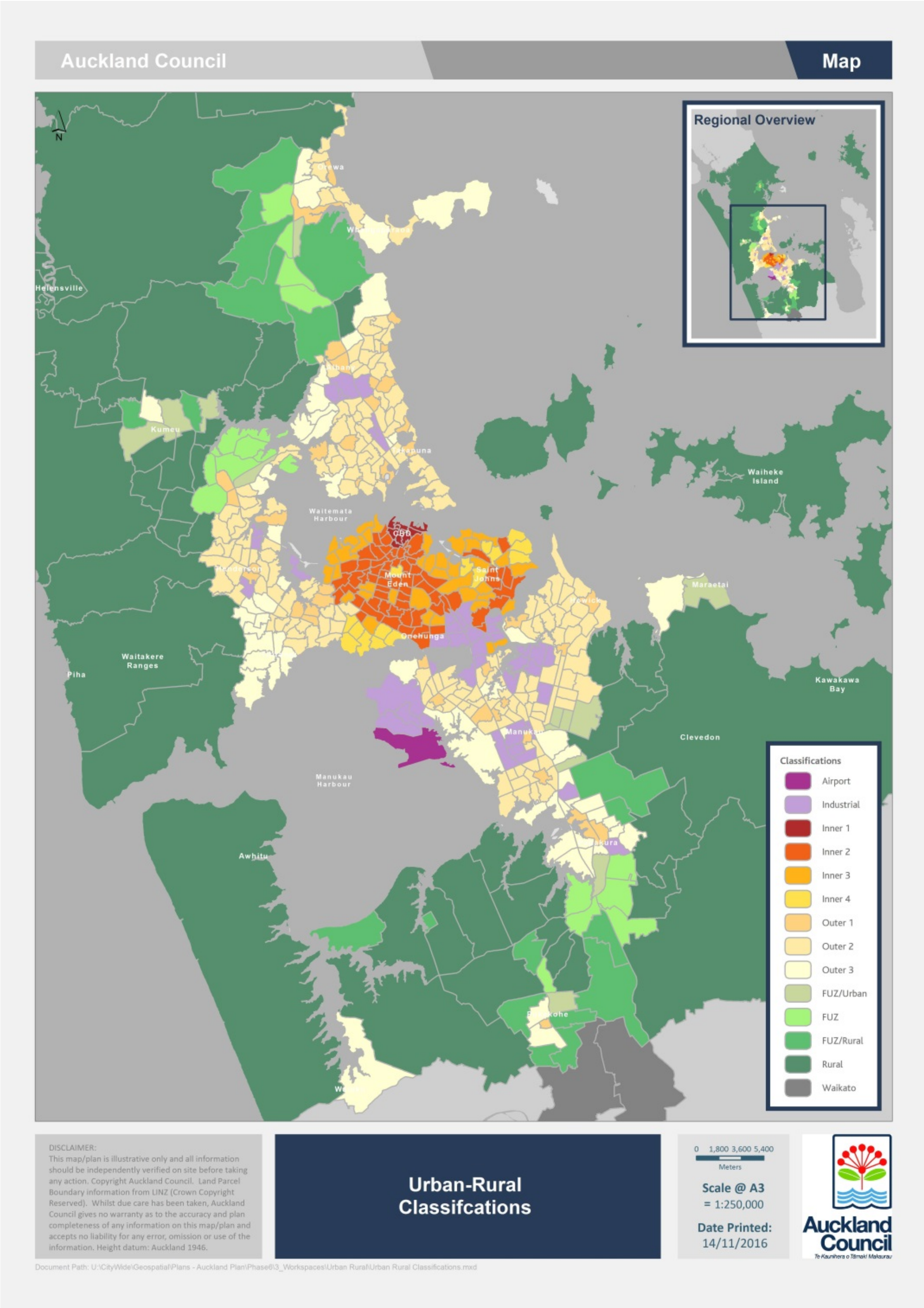


Table 2. Summary of data and information sources used in the assessment

Dataset / Study / Model	Source	Used for
Auckland Transport Model (ART3)[3]	Auckland Transport	Identifying the Vehicle Kilometres Travelled (VKT) for each scenario
Vehicle Emission Prediction Model (VEPM), version 5.2.1	Emission Impossible (2016)	Measuring emission factors (g/km)
Damage costs, local air pollutants	Watkiss (2002) and Austroads (2012)	Transferring and converting the cost to 2017 NZ dollar. Using following converters: http://www.rba.gov.au/calculator/annualDecimal.html http://www.xe.com/currencyconverter/convert/?Amount=483%2C392.89&From=AUD&To=NZD
Population and number of households in 2045	2013 census result and the medium growth projection by Statistics New Zealand to 2046 (as in December 2016)	Calculating number of people who would be affected
Damage cost for CO_2	New Zealand Transport Agency (2016), Austroad (2012) and consultation with Ministry of business Innovation and Employment, (MBIE), Auckland Council and Ministry for the Environment (MfE)	Defining two options for damage cost per tonne CO_2 was converted to 2017 NZ dollar
2012 Home Heating Survey Result	Stones-Havas (2014)	Estimating the proportion of woodburners in each area of Auckland
Domestic Fire Emission Prediction Model (DFEPM)	Emission Impossible (2016)	Estimating number of solid fuel appliances in 2046
Number of woodburners in each CAU	2013 census, statistics New Zealand	Estimating the damage cost in each area
Dwelling age	Balderston (2013)	Estimating the number of dwelling that would be redeveloped in future.
Winter day PM emission (kg/day)	Xie et al. (2010)	Estimating domestic air pollution reduction in a year as the result of domestic fire
Urban planning that sustains water bodies: southern RUB case study	Moores et al. (2013)	Discussing the result of the study on impact of development scenarios on waterbodies in a catchment in Auckland.
Urban development and the NPS-FM: Lucas Creek catchment case study	Moores et al. (2016)	Discussing the result of the study on impact of development scenarios on waterbodies in a catchment in Auckland.
Cost of soil loss	Sandhu et al. (2007) and McDonald et al. (2009)	Estimating the cost of soil loss under each scenario.

[3] Auckland Regional Transport model.

2.0 Air quality

Emissions from anthropogenic activities in urban areas, such as transport and home heating, can have a significant impact on local and global air quality. However, the subsequent impacts in terms of health effects are influenced by land use type and intensification.

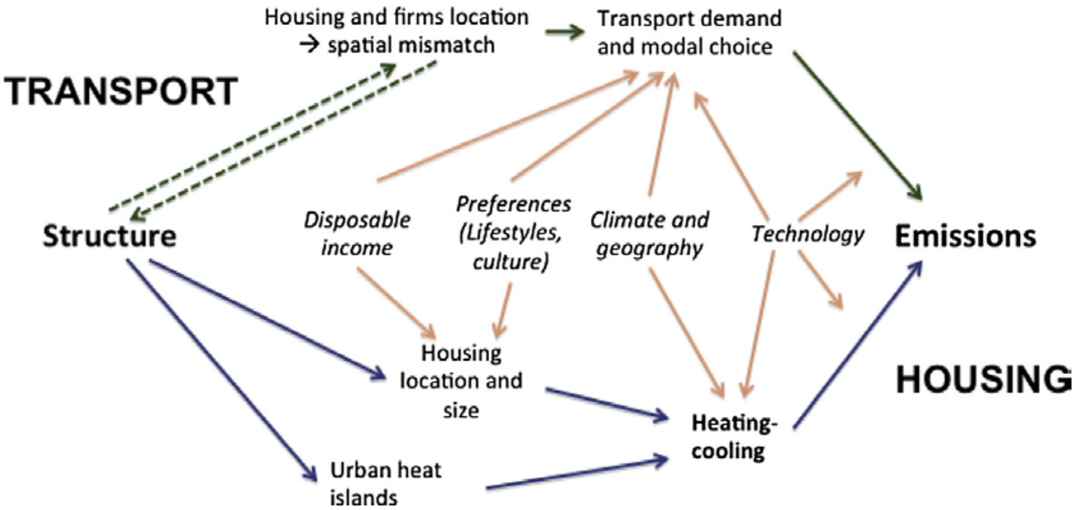
Exposure to harmful emissions (such as PM_{10}) increases premature death of affected populations. The resultant social costs from poor local air quality are substantial and are comparable with other major social costs, such as the cost of road crashes and congestion (Nunns, 2015).

> "*The health impacts of poor air quality are large in magnitude. According to the updated Health and Air Pollution in New Zealand Study (HAPINZ), in 2006 anthropogenic air pollution from fine particles (PM_{10}) in the Auckland region led to approximately 290 premature deaths and 493,000 restricted activity days (Kuschel et al., 2012). This had an overall estimated social cost of $1.07 billion per year for the Auckland region (in New Zealand dollars as at June 2010). The HAPINZ model indicates that unless policies are implemented to reduce emissions, these health costs will rise in line with Auckland's population growth. These estimated health costs may understate the true social cost of air pollution. HAPINZ focuses on the health impacts of PM_{10} emissions, while excluding or only partially accounting for the impacts of other priority pollutants, including particles with a diameter of less than 2.5 microns ($PM_{2.5}$), NO_2, and SO_2*" Nunns (2015) p.10.

In addition, urban planning can have an impact on the growing threat from climate change, a global air quality issue (New Zealand Productivity Commission, 2016).

The components of urban form (spatial structure) that have the greatest impact on local and global air quality are the transport and residential sectors, e.g. through transport demand, modal choice and options for home heating (as shown in Figure 3).

Figure 3. Potential links between spatial structure and emissions



Adapted from: Burgalassi and Luzzati (2015)

The following sections discuss the likely impact of each of the three urban form scenarios on emissions and consequent impacts from transport and home heating in Auckland in 2046.

2.1 Transport emissions

Transport-related air pollution, energy consumption, and greenhouse gas (GHG) emissions depend primarily on vehicle kilometres travelled (VKT) and secondarily on traffic flow behaviour, especially speed and congestion (Ewing et al., 2008).

Litman (2016) calculated a weighted average elasticity of vehicle miles travelled (VMT) based on the result of nine studies. The result shows that doubling the neighbourhood population density reduces per capita vehicle travel by 4 per cent. This was confirmed in a recent literature review (Nunns and Rohani, 2016) which showed that a higher population or employment density typically correlates with lower per capita vehicle travel (see Table 1).

Newman and Kenworthy (2011) also found a statistically strong inverse relationship between density and per capita vehicle travel in 58 high income cities (see Figure 4).

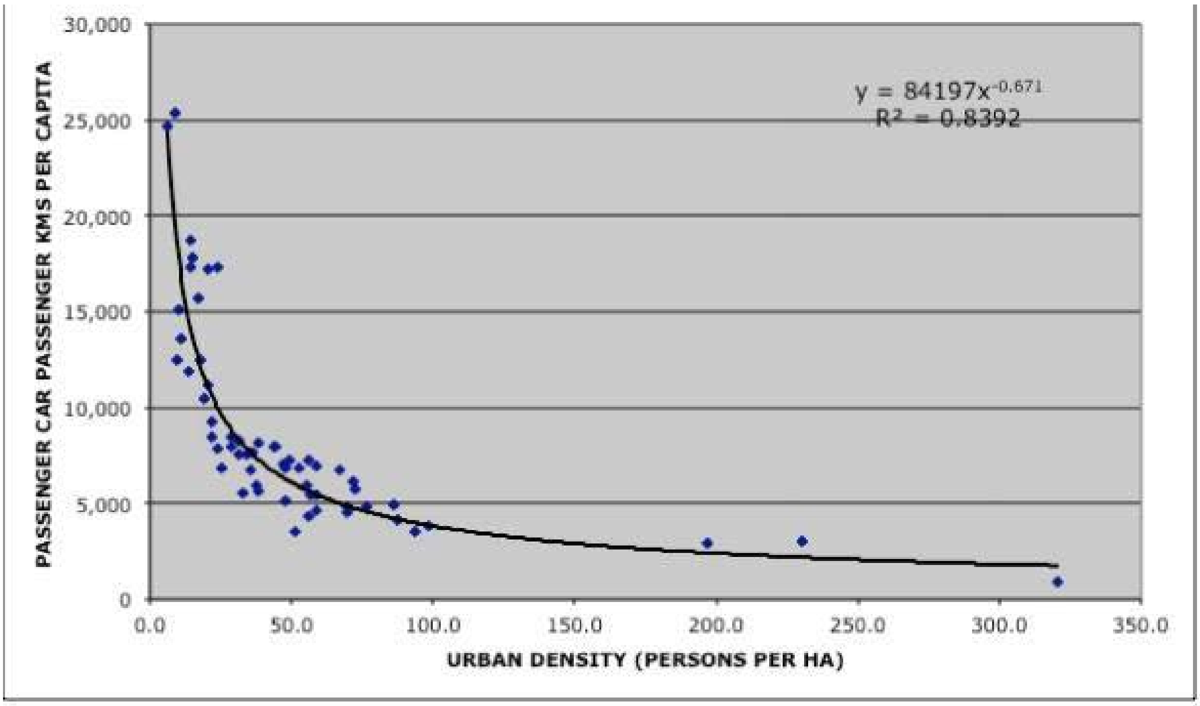
Table 3. Relevance of the population density, vehicle use and VKT

Study	Finding
Ewing, Pendall and Chen (2002)	a higher sprawl index[4] is associated with higher per capita vehicle ownership and use, and lower use of alternative modes.
Ewing and Cervero (2002 and 2010)	doubling neighbourhood density reduces per capita vehicle travel by 5%.
Manville and Shoup (2005)	1% population density increase is associated with a 0.58% reduction in VKT.
Ewing and Cervero (2010)	doubling urban densities typically reduces per capita vehicle travel 25-30%.
McMullen and Eckstein (2011)	long-run elasticity of vehicle travel with respect to population density to be -0.0431
Turcotte (2008)	negative correlation between local density, automobile mode share and average daily minutes devoted to automobile travel.
Mindali, Raveh and Salomon (2004)	the specific density-related factors that affect vehicle use, including per capita vehicle ownership, road supply, CBD parking supply, mode share and inner-area employment.
Barnes (2003)	employment density affects commute mode share more than residential density.
Frank and Pivo (1995)	automobile commuting declines significantly when workplace densities reach 50-75 employees per gross acre.
Bronzini (2008)	employment and industrial density also seems reduce truck VKT per capita.
Levinson and Kumar (1997)	as land use density increases, both travel speeds and trip distances tend to decline.

Source: Litman (2016) and Nunns and Rohani (2016)

[4] They developed a sprawl index based on 22 variables related to land use density, mix use, street connectivity and commercial clustering.

Figure 4. Population density versus private car travel



Source: Newman and Kenworthy (2011)

The trends in VKT predicted using the Auckland Transport model (ART3) for the three urban form scenarios (shown in Table 4) are consistent with the literature, with the expansive and intensive scenarios resulting in the highest and lowest VKT, respectively. These extremes reflect the fact that inner city residents are more likely to take walking, cycling and public transit trips, and shorter car trips than outer location residents.

Table 4. Total VKT for the three urban form scenarios in 2046

Scenario	Annual VKT (million)
I9 (Baseline)	10,087
Intensive growth	9,616
Expansive growth	10,940

Source: Auckland Transport model (ART3)

Another factor that impacts air quality is traffic congestion, which generates higher emissions than if vehicles are travelling freely. There is evidence showing that intensive development increases congestion and generates more air pollution (Krupp and Acharya, 2014).

A recent study by Longley et al. (2016) examined the air quality responses to intensive urban scenarios in Auckland. The authors found that dense building clusters in inner city centre streets reduced dispersion of emissions by approximately five times. Although this work is in progress, their analysis to date suggests that urban intensification worsens air quality, possibly due to poorer dispersion and higher numbers of diesel vehicles (i.e. buses) in these environments.

Major cities suffer higher environmental costs as a result of air pollution because the population density is high and the urban area is extensive. In addition, low speeds and roads that are heavily congested produce higher emissions per kilometre (Watkiss, 2002).

In this study we accounted for both VKT and speeds of both cars and heavy (diesel vehicles). Therefore the negative impact of both higher VKT and lower speed especially for diesel vehicles was measured.

Methodology

The impact of the each development scenario on air quality as the result of different transport outcomes was measured based on changes to the harmful air pollutants which have the greatest impact in Auckland as follows:

- Particulate matter (PM_{10} and $PM_{2.5}$)
- Oxides of nitrogen (NO_x – which includes NO_2 and NO)
- Carbon dioxide (CO_2).

The costs resulting from these emissions in the year 2046 were estimated for each urban form scenario. The following five steps summarise the process of estimating the emission amount by type and emission cost for each scenario.

Step 1: Emission factors (g/km) were generated using the Vehicle Emission Prediction Model (VEPM), version 5.2.1, for vehicle speeds ranging from 10 to 99 km/h. VEPM projects the fleet composition year by year out to 2040 only. Therefore, the fleet composition and resulting emissions factors for 2046 were assumed to be equivalent to those for 2040, which given the timeframe, was not unreasonable.

Step 2: Daily greenhouse gas emissions (CO_2) and harmful emissions (PM and NO_x) were then estimated for both cars and heavy vehicles in 2046 from VKT and speeds using the Auckland Transport model (ART3) for each urban form scenario. They were then converted to tonnes per year, assuming 245 weekdays per year (see Table 5).[5]

Step 3: Damage costs were calculated for the primary local pollutants, PM and NOx, based on the severity of the adverse impact and the availability of data. The source of data for damage cost per tonne of pollutant was Watkiss (2002), which is also recommended by Austroads (2012) to use in assessing damage costs associated with transport projects.

[5] Weekdays were taken as the basis of the analyses due to the impact of working week activities on congestion.

Table 5. Annual weekday transport emissions in 2046 for the urban form scenarios

Pollutant	Vehicle type	Tonnes emitted in 2046 for each scenario		
		I9 (Baseline)	Intensive	Expansive
NOx	Total	3,381	3,282	3,548
	Car	1,410	1,349	1,517
	HCV	1,971	1,933	2,030
PM_{10}	Total	245	237	261
	Car	170	163	183
	HCV	75	74	77
CO_2	Total	1,806,703	1,746,171	1,923,615
	Car	1,300,513	1,249,699	1,402,418
	HCV	506,190	496,472	521,196

Step 4: Australian data from Watkiss (2002) was applied to Auckland, utilising the densities of urban and rural areas of Australian cities to pro-rate the health impact. As the result, the cost associated with each band in the Watkiss (2002) study was correlated to an area with a similar density in Auckland based on the AP's urban-rural classifications (see Figure 2) as follows:

Band 1. Inner areas of large capital cities (Melbourne, Sydney, Brisbane, Adelaide and Perth). This band was correlated to the areas indicated as inner 1 to 4 and includes the proportion of Auckland population in these areas in 2046 under each scenario.

Band 2. Outer areas of large capital cities. These areas have lower population density than the central areas, but have ozone problems and therefore secondary pollution effects. This band has not been considered in our assessment.

Band 3. Other urban areas. This includes smaller capital cities (Canberra, Hobart and Darwin), and other urban areas. This band was correlated to the areas indicated as outer 1 to 3 and includes the proportion of Auckland population in these areas in 2046 under each scenario.

Band 4. Non-urban areas. These areas have very low population densities and no ozone problems. This band was correlated to the areas indicated as FUZ, Industrial and rural and includes the Proportion of Auckland population in these areas in 2046 under each scenario.

Table 6 summarises the process followed to convert the damage costs from AUD 2002 to NZD 2017.

Table 6. Process followed to convert the Australian damage costs for a tonne of particulates (PM_{10}) and NO_X to New Zealand damage costs

AUD 2002	Band 1	Band 2	Band 3	Band 4
PM_{10}	$341,650	$93,180	$93,180	$1,240
NOx [6]	$1,750	$1,750	$260	$0

Source: Watkiss 2002 p.35

AUD 2016	Band 1	Band 2	Band 3	Band 4
PM_{10}	$483,392	-	$131,838	$1,754
NOx	$2,476	-	$367	$0

Source: Reserve Bank of Australia Inflation calculator
http://www.rba.gov.au/calculator/annualDecimal.html

NZD 2017[7]	Inner	-	Outer	FUZ, Industrial and Rural
PM_{10}	$518,973.88		$141,574.04	$1,884.14
NOx	$2,658.86		$395.06	

Source:http://www.xe.com/currencyconverter/convert/?Amount=483%2C392.89&From=AUD&To=NZD http://www.rbnz.govt.nz/monetary-policy/inflation-calculator

Table 7 shows the population density breakdown by area type for the three scenarios.

Table 7. Proportion of population in each density area groups of the growth scenarios

Areas grouped by population density	I9 (Baseline) scenario	Intensive scenario	Expansive scenario
Inner	28%	33%	21%
Outer	52%	52%	54%
FUZ, Industrial and Rural	20%	15%	25%
Total	100%	100%	100%

Step 5: Damage costs for CO_2 were assessed using two estimations of social cost of CO_2 suggested by New Zealand Transport Agency (NZTA) (2016) at NZD 2017 $53.13/tonne[8] and by Austroad (2012) at NZD 2017 $63.24/tonne[9]. These were considered reasonable based on consultation with experts from the Ministry of Business Innovation and Employment (MBIE) (2016), Auckland Council and the Ministry for the Environment (MfE).

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[6] More recent data from DEFRA (2015) suggest that the health impacts associated with NOx may be comparable those for PM_{10} in inner city locations but no data exist for an Australasian city. Therefore, it is likely that a figure of $2,602 per tonne NOx is low.
[7] The prices converted and inflated to the first quarter of 2017.
[8] This is the figure converted to NZD 2017 using consumer price index (CPI). The estimated social cost of CO_2 in the NZTA report is at NZD 2004 $40.
[9] This is the figure converted to NZD 2017 using the same sources mentioned in table 4. The estimated figure cost of CO_2 in the Austroad report is at AD 2010 $52.4.

Although the emission in the intensive urban form scenario are lower than in the two other scenarios (Table 5), the total health impact of this scenario is higher than for the others (see Table 8). This reflects the increased numbers of people exposed to air pollution in the more densely populated area.

Table 8. Cost of local air pollution (PM_{10} and NOx) for 2046, $million (NZD 2017)

Pollutant	I9 (Baseline) scenario	Intensive scenario	Expansive scenario
PM_{10}	$56.68	$60.45	$52.16
NOx	$3.33	$3.66	$2.89
Total cost	$60.01	$64.11	$55.05

Table 9 shows the estimated damage cost of greenhouse gas emissions under each of the development scenarios. Unlike (local) harmful emissions, the (global) impact of greenhouse emissions is not directly related to local population density. Therefore the result for both cost scenarios shows higher damage costs associated with higher VKT, i.e. the expansive scenario as opposed to the intensive.

Table 9. Cost of greenhouse gas pollution (CO_2) in 2046, $million (NZD 2017)

CO_2 price	I9 (Baseline) scenario	Intensive scenario	Expansive scenario
$53.13/tonne	$95.99	$92.77	$102.20
$63.24/tonne	$114.27	$110.45	$121.67

In summary:

- Although the estimated VKT and emissions under the intensive scenario are lower than those in the two other scenarios, the resulting total damage cost of local air emissions (PM_{10} and NO_x) is higher. This reflects the higher damage cost in the intensively populated areas.
- Taking the higher carbon price the total cost of transport emissions in 2046 is higher for the expansive scenario at $172.97 million than the intensive scenario at $170.86 million. Both would be higher than the I9 (baseline) scenario at $170.59 million.[10]

[10] Costs are calculated in 2016 prices.

2.2 Home heating emissions

Domestic fires used for home heating in winter are a major source of air pollution in the Auckland region, contributing 41 per cent of total annual PM_{10} emissions and 43 per cent of $PM_{2.5}$ emissions in 2011 (Auckland Council, 2012a). The annual social costs due to health effects associated with domestic fire pollution are estimated at more than $411 million (2010 NZD) for the Auckland region (Kuschel et al., 2012).

A survey undertaken in 2012 by Stones-Havas (2014) found that 26.2 per cent of Auckland houses used some form of solid fuel burner (see Table 10). The survey found that central, rural and west Auckland are the areas with the most solid fuel burners, with wood being the primary solid fuel[11] used.

Solid fuel burners include open fires, enclosed wood burners, multi-fuel burners and pellet burners, which emit 31, 60, 9 and 0.1 per cent of domestic fire PM_{10} emissions respectively (Rohani et al., 2014).

Table 10. Proportion of solid fuel heating appliances used in the main living area of homes in Auckland in 2012, by type and area

Area	Papakura	Rural Auckland	South Auckland	East Auckland	Central Auckland	West Auckland	North Shore	Total Auckland
Open fire	0.3%	0.6%	0.3%	0.3%	1.9%	0.3%	0.7%	4.5%
Wood burner	1.7%	4.1%	1.5%	1.6%	4.2%	4.0%	3.1%	20.1%
Multi fuel burner	0.1%	0.1%	0.1%	0.1%	0.3%	0.3%	0.2%	1.1%
Pellet fire	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.3%
None of these	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.2%
Don't know	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
Total solid fuel burners	**2.2%**	**4.9%**	**2.0%**	**2.0%**	**6.5%**	**4.6%**	**4.0%**	**26.2%**

Source: Stones-Havas (2014)

According to the Auckland Council (2012b), Air, Land, Water Plan (ALWP), new open fires and new multi-fuel burners are only permitted within the urban area if they meet a PM_{10} emission limit of 4.0 g/kg fuel. This essentially bans new open fires as current technologies cannot meet this limit.

[11] For this reason, the term woodburner is sometimes used as a substitution for the term solid fuel burner.

"*Any discharge of contaminants into air from new solid fuelled domestic fires in Urban, Coastal Marine and Industrial Air Quality Management Areas shall discharge at a particulate emission rate of no more than 4.0 g/kg of fuel burned (for appliances without catalytic combustors) and 2.25 g/kg (for appliances with catalytic combustors) determined using the New Zealand Standard AS/NZS 4013:1999 (Domestic Solid Fuel Burning Appliances – Method for determination of flue gas emission) or a functional equivalent test method for batch-fed appliances on the list of approved methods held by the ARC.*", Auckland Council (2012b) p.4-20.

Under the Resource Management Act (National Environmental Standards for Air Quality) Regulations 2004 (the NESAQ), new domestic woodburners installed on properties smaller than 2 hectares are only permitted if they emit less than 1.5 g/kg and meet the thermal efficiency standard. These low emitting woodburners are also referred to as "NES woodburners". The NESAQ limits do not apply to open fires or multi-fuel burners.

Outside the urban areas, all new open fires and multi-fuel burners are permitted according to the ALWP regardless of emissions. However, on sections smaller than 2 hectares, all new woodburners are only permitted if they meet the NESAQ. On sections larger than 2 hectares, all new woodburners are permitted regardless of emissions.

Table 11 summarises rules and legislations in relation to new burner installations (including replacing existing ones).

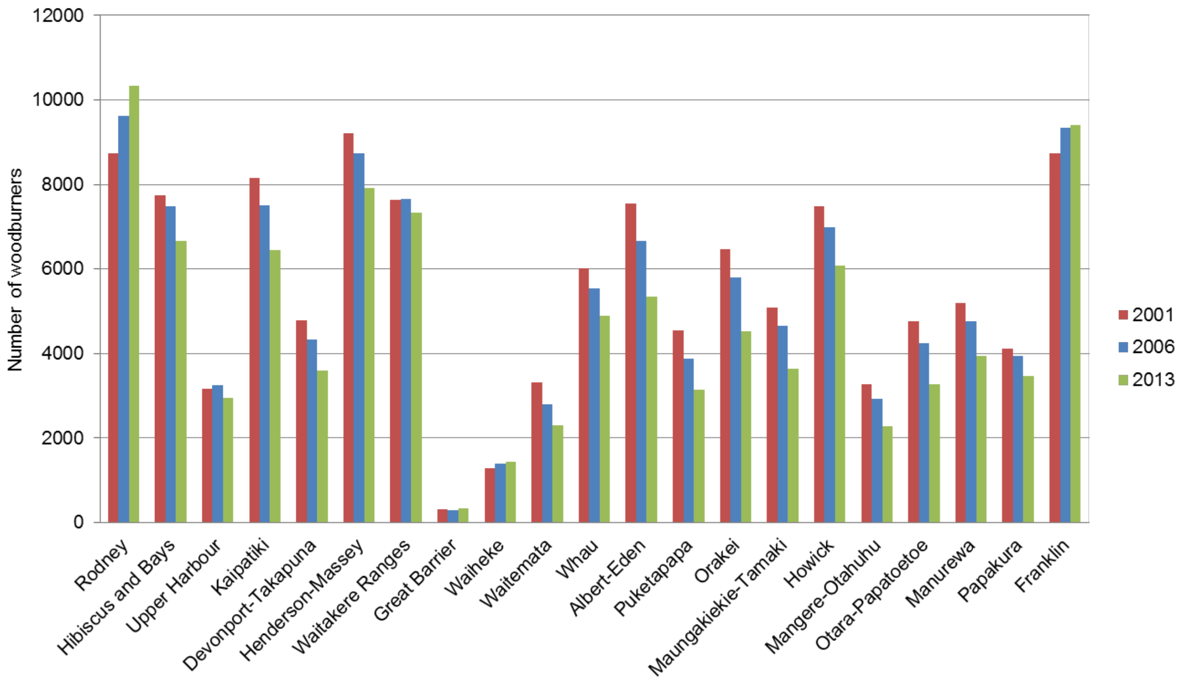
Table 11. Summary of rules for new burner installations

Type of appliance	Inside "urban" areas	Outside "urban" areas
Open fire	According to ALWP, must meet 4.0g/kg (essentially banned)	Allowed regardless
Woodburner (includes pellet burners)	According to NESAQ, must meet 1.5g/kg	According to NESAQ, must meet 1.5g/kg if section <2.0 hectares. If section >2.0 hectares, allowed regardless
Multifuel burner (wood/coal)	According to ALWP, must meet 4.0g/kg	Allowed regardless
Other types of burners	According to ALWP, must meet 4.0g/kg	Allowed regardless

In this analysis, it was assumed that the number of solid fuel burners would not increase in the urban area and it would not change significantly in the rural area. Even if the number of burners increase in rural area, the cost of damage is not significant due to the low density population. Therefore, there would be no difference between the urban form scenarios in terms of additional solid fuel burners and their associated negative externalities. Instead, the redevelopment of inner city areas under both the baseline and the intensive scenarios compared to the expansive scenario would improve air quality by reducing the number of domestic fires.

The latest census data shows that the numbers of woodburners in central Auckland and other urban areas of the city continued to decrease in 2013 compared to two previous census years, by 2.7 and 1.8 per cent on average per annum respectively (Statistics New Zealand, 2013). However, the number of woodburners has increased in rural Auckland by 0.8 per cent per annum. Figure 5 illustrates the changes in the number of woodburners in Auckland by local board (2001-2013).

Figure 5. Number of woodburners in Auckland local boards 2001-2013 census



Source: Statistics New Zealand

Methodology

As with transport emissions, the pollutants which have the greatest impact in Auckland are:

- Particulate matter (PM_{10} and $PM_{2.5}$)
- Oxides of nitrogen (NO_x – which includes NO_2 and NO)
- Carbon dioxide (CO_2).

In this analysis only the social costs of particulate matter and NO_X emissions from domestic fires were calculated.[12]

The potential costs resulting from PM_{10} and NO_x emissions in 2046 were calculated for each of the urban form scenario, as follows:

[12] For domestic home heating, the vast majority of the CO_2 emissions come from the burning of wood which is a renewable source and therefore these emissions are carbon neutral and are not shown in the analysis.

Step 1: The numbers of burners for business as usual (without development scenarios) were calculated using the result of Domestic Fire Emission Prediction Model (DFEPM) for 2033 (the latest year in the model). The numbers were then extrapolated linearly to estimate the number of burners in 2040. It was assumed that 2046 would be same as 2040. Table 12 shows the number of solid fuel burners in 2046 by type of burner.

Table 12. Estimated number of solid fuel appliances by type of burner in 2046 for business as usual (without development scenarios)

Type of burner	Business as usual from DFEPM Number of burners
Pre-1991 burners	-
Post-1991	-
Post-2005	104,708
Multifuel	-
Open fire	1,733
Pellet	5,103
Total appliances	**111,544**

Step 2: The reduction in the number of burners as a result of each scenario was calculated using the following assumptions and datasets:

- It was assumed that older dwellings would be replaced with higher density dwellings. The classification of older dwellings included buildings with the age of 80-100 years by 2046 (originally built in 1940-1960), not historic dwellings with ages above 100 years that are more likely to be considered as heritage buildings. The following datasets were used to estimate the number of these older dwellings under each scenario:
- The numbers of woodburners per census area unit (CAU) were taken from the 2013 census (Statistics NZ)
- The dwelling ages per parcel, meshblock (MB) and CAU and Art Zone (ART3) were taken from Balderston (2013).
- The number of households was taken from the urban form scenarios data using (ART3).

The data sources were then linked using the MB, CAU and ART3 codes to estimate the number of solid fuel burners that would be reduced under each scenario. Table 13 summarises the reductions for each of the defined areas.

Table 13. Number of solid fuel burners removed as the result of redevelopment under each of the scenarios

Area	I9 (Baseline)	Intensive	Expansive
Inner 2	875	1580	423
Inner 4	197	304	136
Inner 3	430	675	236
Outer 2	919	801	1004
Outer 1	1054	1151	718
Outer 3	374	309	456
Total	**3849**	**4821**	**2971**

Source: Authors' estimate

Step 3: The emission factors estimated using the following assumptions and datasets:

- Winter day[13] PM_{10} emissions (in kg/day) were estimated from PM_{10} emission factors (in g/kg wood) and the amount of wood burned (in kg/day) for each type of burner using data extracted from Xie et al. (2010).
- PM_{10} emissions for a typical winter's day were converted to annual emissions (in t/yr) by multiplying the values by 31 (the number of days in July) and dividing them by 29 per cent (the fraction of annual emissions typically emitted in that month).
- Annual NO_x emissions (in t/yr) were assumed to be 9 per cent of the annual PM_{10} emission (in t/yr) based on typical emission ratios for woodburning.

Table 14 shows the emissions factors used and the estimated annual emissions of PM_{10} and NO_x in 2046 for business as usual in 2046 (without development scenarios).

Table 14. Estimated annual emissions of PM_{10} and NOx in 2046 for business as usual (without development scenarios)

Appliance type	PM_{10} emission factor (g/kg wood)	Amount of wood burnt (kg/day)	Total winter day PM_{10} (kg/day)	Annual PM_{10} (t/yr)	Annual NO_x (t/yr)
Post 2005 woodburner	3.7	14	5,424		
Open fire-wood	12	10	208		
Pellet burner	1.4	5	36		
Total			**5,668**	**606**	**55**

Source: Xie et al. (2010), and RIMU calculation

[13] Based on a survey results for July.

Step 4: The damage cost associated with the local emissions from domestic fire estimated for inner, outer and rural areas use the same method described in the transport emission methodology steps 3- 5.

Table 15 shows the estimated damage cost per tonne of PM_{10} and NO_x in NZD 2017.

Table 15. Estimated damage cost for a tonne of PM_{10} and NO_x (NZD 2017) by area

Area	PM_{10}	NO_x
Inner	$518,974	$2,659
Outer	$141,574	$395
Rural	$1,884	$0

Source: Watkiss 2002 p.35 and RIMU's calculation

Step 5: Total damage costs for business as usual and the cost savings as result of each scenario were then calculated using the number of burners reduced under each scenario and the damage cost per burner for each area type. It is assumed that open fires would be removed first and then the rest of the reduction would come from removing post 2005 woodburners. All of the inner areas grouped together as well as the outer areas to estimate damage cost per tonne of emission in each area group as per Table 15. Table 16 shows the local emission and the damage cost associated with the total number of solid fuel burners in 2046.

Table 16. Estimated number of woodburners, their emissions and associated damage cost in 2046 (NZD 2017) by area

Area	Number of appliances	Annual PM_{10} (t/yr)	Annual NO_x (t/yr)	Total cost PM_{10} $million	Total cost NO_x $million
Inner	27,673	150.30	13.53	$78.00	$0.08
Outer	63,010	342.23	30.80	$48.45	$0.00
Rural	20,861	113.31	10.20	$0.21	-
Total	**111,544**	**606**	**55**	$126.67	$0.09

Source: The DFEPM results and RIMU's calculation

Step 6: Total damage cost reductions as a result of removing solid fuel burners were calculated using the data provided in steps 2 and 4, using the same method in step 5. Table 17 shows the local emissions and damage cost reductions as the result of each scenario. The final results presented in Table 18 show the total damage costs after considering the cost reductions as result of each scenario.

Table 17. The reductions in local emissions (PM_{10} and NO_x) and damage costs estimated for each scenario (NZD 2017)

Area	Reduced PM_{10} t/yr			Reduced NO_x t/yr			Damage cost saving PM_{10} $million			Damage cost saving NO_x $million		
	I9	Intensive	Expansive	I9	Intensive	Expansive	I9	Intensive	Expansive	I9	Intensive	Expansive
Inner 2	4.8	8.6	2.3	0.4	0.8	0.2	2.5	4.5	1.2	0.001	0.002	0.001
Inner 4	1.1	1.7	0.7	0.1	0.1	0.1	0.6	0.9	0.4	0.000	0.000	0.000
Inner 3	2.3	3.7	1.3	0.2	0.3	0.1	1.2	1.9	0.7	0.001	0.001	0.000
Outer 2	5.0	4.4	5.5	0.4	0.4	0.5	0.7	0.6	0.8	0.000	0.000	0.000
Outer 1	5.7	6.3	3.9	0.5	0.6	0.4	0.8	0.9	0.6	0.000	0.000	0.000
Outer 3	2.0	1.7	2.5	0.2	0.2	0.2	0.3	0.2	0.4	0.000	0.000	0.000
Total	**21**	**26**	**16**	**1.9**	**2.4**	**1.5**	**6.0**	**9.0**	**3.9**	**0.002**	**0.004**	**0.001**

Table 18. Total damage cost under each scenario for each area type considering the cost saving under each scenario (NZD 2017)

Area	Total damage cost PM_{10} $million			Total damage cost NO_x $million		
	I9	Intensive	Expansive	I9	Intensive	Expansive
Inner	$75.31	$74.63	$75.93	$0.03	$0.03	$0.04
Outer	$46.78	$46.36	$47.16	$0.01	$0.01	$0.01
Rural	$0.21	$0.20	$0.21	$-	$-	$-
Total	**$122.30**	**$121.19**	**$123.29**	**$0.05**	**$0.05**	**$0.05**

In summary:

- All three growth scenarios in 2046 – baseline, intensive and expansive – would reduce local home heating emissions (PM_{10} and NO_x) and their associated damage costs relative to current business as usual due to the prediction of reduced number of burners. The cost savings are estimated to be the highest for intensive scenario ($9 million) – more than double the cost saving of the expansive scenario and 50 per cent greater than the cost saving under the baseline scenario.

- The total cost of home heating emissions in 2046 would be higher for the expansive scenario at $123.35 million than the intensive scenario at $121.24 million and the baseline scenario at $122.35 million. The lowest damage costs are for the intensive scenario.

3.0 Water bodies

Urban development can be a threat for freshwater ecosystems in New Zealand along with several other factors[14]. Many rivers, streams and lakes particularly in coastal areas are at risk of environmental degradation following population growth and development (Winterbourn, 2016).

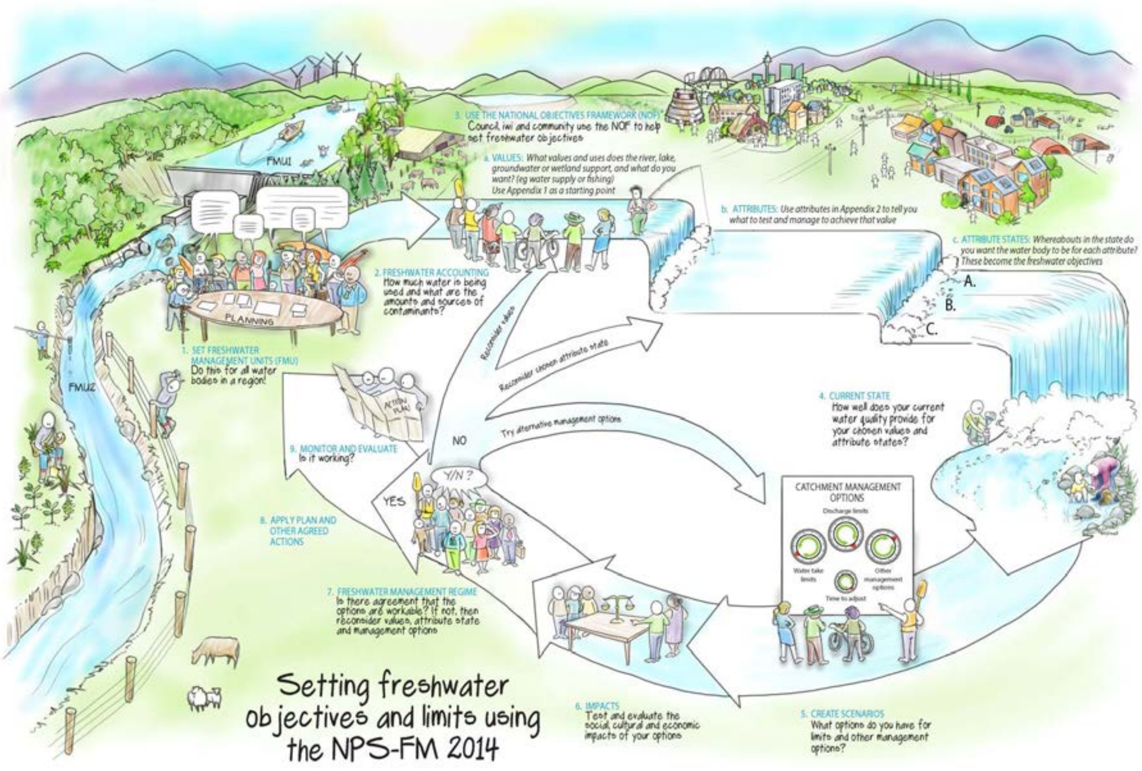
According to the Auckland Council (2015), the Auckland region is 75 per cent water. In total there are approximately 11,117 km² of ocean and 1800km of coastline. There are also 16,500km of permanently flowing rivers, 72 natural and artificial lakes, and many aquifers providing essential resources for our people and animals in the region. The city is situated on an isthmus between the Waitematā and Manukau harbours. This urban positioning provides magnificent views and connections with the water, but has also has a strong influence on the health of our freshwater and marine environments. Auckland Council (2015) has found evidence of the degradation of freshwater as the result of intensive land use activities, primarily in and around the urban area.

Historical evidence on the impact of urban development on water quality shows that earthwork activities, sediment and heavy metals conveyed in stormwater have affected water quality in New Zealand's catchments (Moores et al., 2016). Car usage on high use roads and carparks that are exposed to rainfall are also recognised as potentially High Contaminant Generating Activities (HCGAs) (Kettle and Kumar, 2013). Carbines and Vaughan (2013) suggest that future land development would affect the whole environment including the existing habitats and the plants and animals living there, as well as the recreational and aesthetic values of the receiving environment and the functional capacity of the environment to deliver ecosystem services that benefit humans. Therefore, water quality mitigation within water bodies is a priority for central and local governments under the Resource Management Act (RMA) (1991) and other related legislation.

Auckland Council is responsible for implementing the National Policy Statement for Freshwater Management (NPS-FM), to mitigate freshwater degradation in the region. This means the council is required to carry out its responsibilities under the RMA (1991) for managing fresh water in an integrated and sustainable way using the NPS-FM policy direction. The key objective of the NPS-FM for local authorities is to maintain or improve the overall quality of freshwater in the region (New Zealand Government, 2014). Figure 6 provides an overview of the freshwater objectives and limits setting process under the NPS-FM.

[14] Other factors include mining, forestry, water abstraction, intensification of agriculture, the presence of invasive species and, potentially, climate change.

Figure 6. Overview of the freshwater objective and limit setting process under the NPS-FM



Adapted from: New Zealand Government (2014), p.63

The development scenarios have the potential to introduce sediments and contaminants to freshwater and marine receiving environments in the Auckland region both in the construction and post-development phases. The ongoing population growth and new development make it more challenging for the council to implement the NPS-FM objectives, especially given evidence of the impact of historic and ongoing urban development on Auckland's estuarine receiving environments.

High concentrations of metals, mud and other contaminants (and subsequent poor ecological health) are evident in many muddy upper estuarine areas receiving runoff from older urban and industrial catchments (Moores et al., 2013). The impact of urban development on water bodies has been the focus of many empirical studies internationally[15]. In New Zealand literature the relationship between urban growth and water degradation has been recognised by Green et al. (2004), Green (2008 a&b), Miller et al. (2008), Townsend et al. (2012), Meeres et al. (2013) and Moores et al. (2016). But there is little available research comparing the impact of intensive versus expansive development.

Due to the limited data available and the given time frame, the analysis of the potential negative impact of the scenarios on water bodies was not feasible. Consequently the rest of this section summarises the results of the two most recent and relevant studies on the impact of various development scenarios on water bodies in the Auckland context.

[15] It is discussed in the introduction of this report.

Urban planning that sustains water bodies: southern RUB case study

Moores, et al. (2013) used the Urban Planning that Sustains Water bodies (UPSW) tool in the Southern Rural Urban Boundary (RUB) case study to assess the impacts of future urban development on the values of receiving water bodies within the Pahurehure Inlet. The UPSW tool develops a decision support system (DSS) which models how streams and harbours would react under different urban development scenarios. They compared the likely impact of seven development and water treatment scenarios on environmental indicators of water quality, stream ecology, sediment quality and estuary ecology in 50 years' time. The development scenarios are summarised as follows:

1) The baseline scenario (scenario 1).[16]
2) Development of the core development areas, with varying levels of stormwater.
3) treatment (scenarios 2A-2D) and with best levels of earthwork controls (scenario 2E).
4) Development of the core and additional areas in the centre-south of the study area (scenario 3), the Pukekohe focus (scenario 5) and corridor focus (scenario 6).
5) Development of the core and additional areas in the north of the study area (scenario 4), including the West-East focus (scenario 7).

Based on predicted changes in environmental indicators, the findings include the following:

- Negative effects on the receiving environment in the study area would increase significantly anyway with or without new development (i.e. under scenario 1).
- These effects would be due to sediment from ongoing rural land use in the southern and western catchments of the Pahurehure Inlet and inputs of metals from existing urban land use in northern and eastern catchments.
- Any new development utilising current or reduced earthworks and stormwater treatment controls is predicted to have substantial additional effects on the receiving environment over and above predicted baseline effects.
- If the best available earthworks and stormwater treatment controls are applied and achieved then it is predicted that the effects of any new development could be maintained at similar levels to (or even slightly improve on) those predicted under the baseline scenario.
- Although the effects from development could be mitigated using best possible earthworks and stormwater treatment, several environmental indicators are predicted to worsen over time, due to the effects of existing land use outside the development area (Auckland Council, 2015).
- Concentrating development in a limited number of catchments also concentrates the effects of the development in associated estuarine areas while spreading development over more catchments spreads the effects over more estuaries.

[16] The baseline scenario was a set of predictions made by Moores and Timperley (2008), South-eastern Manukau (SEM) Harbour contaminant study. As a result, all future urban development was assumed to occur inside the existing urban footprint as defined by the 2013 Rural Urban Boundary.

Urban Development and the NPS-FM: Lucas Creek Catchment Case Study

More recently the UPSW, DSS was used by Moores et al. (2016) to predict the impact of five land use change scenarios on water bodies in the Lucas Creek catchment over the period of 2010-2060. The scenarios are summarised as follows:

1) Low density greenfield development (2010 land use)[17]
2) higher density greenfield and infill development (2010 land use)
3) brownfield development (replacement of areas of existing industrial development with high density residential development) (2010 land use)
4) low density greenfield development (1960 land use)[18]
5) higher density greenfield development (1960 land use).

Once development is completed, all five scenarios accommodate the same number of dwellings, with different densities and therefore different urban footprints. Figure 7 shows the land use breakdown for scenarios 1-3.

Moores et al. (2016) modelled contaminants, associated with urban development, including sediment and the metals copper, lead and zinc. The results of the study indicate that:

- A high level of contaminant control would be required to maintain and improve water quality following urban development and may require measures over and above 'best practice' stormwater treatment and erosion and sediment control, including Water Sensitive Design (WSD) development approaches and retrofitting stormwater treatment in areas of historic development.
- Based on predictions of sediment metal concentrations and the Benthic Health Index, the results of the study indicate a reduction in estuary environmental quality under all urban development scenarios. This reflects the depositional nature of the estuary, which acts as a sink in which contaminants delivered from its catchment accumulate.
- The urban development effects should be measured and mitigated in conjunction with the undeveloped, rural parts of a catchment.
- Further development of catchments which are already partly developed (and which already contain some level of mitigation) may be more cost-effective[19] than attempting to mitigate the effects of development in greenfield catchments.
- In order to benefit from the potential gains associated with lower metal loads delivered from high density, infill, form of development, it may also be necessary to address water quality issues associated with undeveloped rural parts of catchments where these exert a significant influence over catchment water quality.
- In the absence of the counteracting influence of higher sediment loads from rural land, higher density and/or brownfields development could be expected to deliver

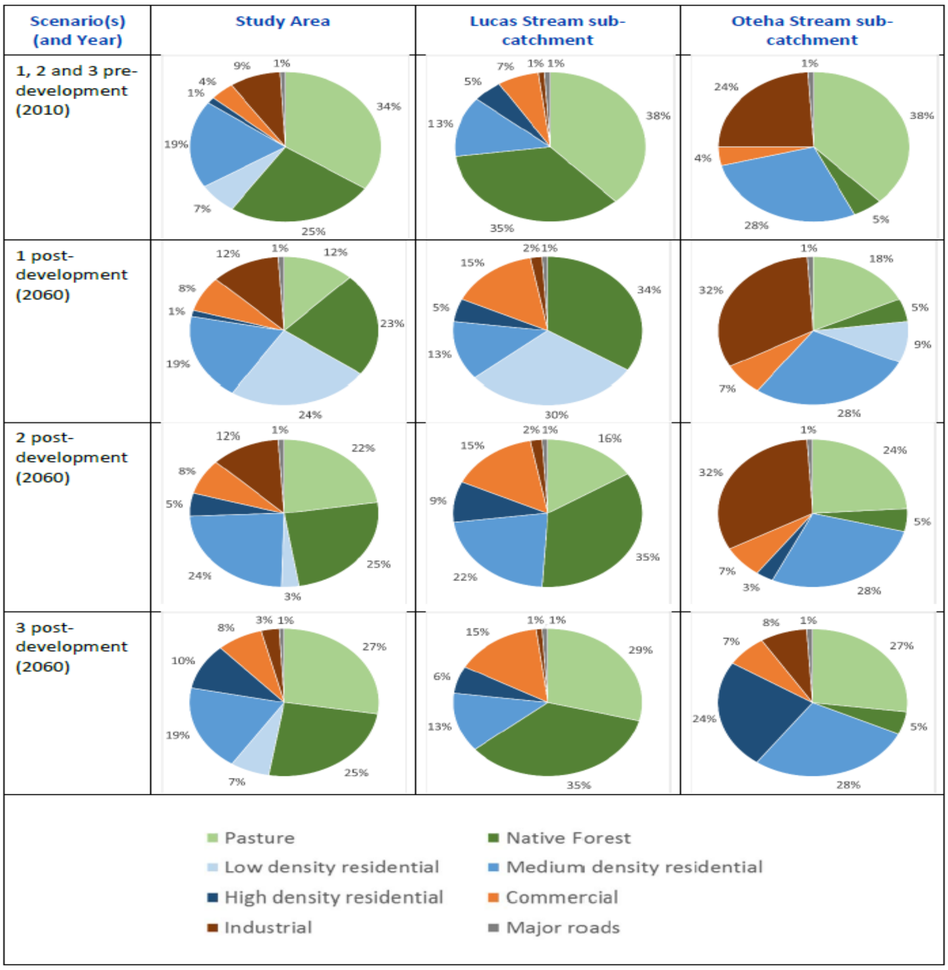
[17] It includes the historic urban development that occurred in the Lucas Creek prior to 2010.

[18] The hypothetical situation of there having been no urban development in the catchment over the 1960-2010 period. This means in these scenarios all the development (equivalent to actual historic + projected future) happens over the period 2010-2060.

[19] The cost effectiveness refers to the cost associated with achieving some desired objective. Desired objective in the case of this case study is to at least maintain the score of the water quality indicator at its pre-development level.

better water quality outcomes than more extensive, low density development. These results therefore provide a further illustration of the value of taking a whole-of-catchment approach that considers how best to manage both urban and rural effects on water quality.

Figure 7. Land use breakdown for the three main scenarios



Adapted from: Moores (2016), p.72

The cost of mitigation was predicted under each development scenario in both sub catchments, Lucas and Oteha, using various mitigation models. For each of the five land use change scenarios, a number of alternative contaminant and stream management interventions were considered. The mitigation measures labelled as variants ‘A’ to ‘H’ were applied in additive fashion to each land development scenario, (See Table 19).

Table 19. Mitigation applied in variants 'A' to 'H' of the five land use change scenarios

Label		Description
A	Status quo	"Levels of earthworks controls (75% removal of TSS) and stormwater treatment (either unchanged from the historic level of stormwater treatment or, in areas of new development, 75% removal of TSS and 'medium' metals removal."
B	Best practice	"Levels of earthworks controls (90% removal of TSS), stormwater treatment (90% removal of TSS and 'high' metals removal) and zinc source control of roofs (use of lowest zinc-yielding materials7) in areas of new development."
C	Water Sensitive Design (WSD) development	"Projected additional dwelling numbers accommodated with a smaller impervious footprint."
D	Retrofitting best practice	"Stormwater controls to areas of existing development."
E	Vehicle component source control	"Lower copper-yielding brake pads and lower-zinc yielding tyres."
F	A+ Extensive and high quality riparian planting	"Levels of earthworks controls (75% removal of TSS) and stormwater treatment (either unchanged from the historic level of stormwater treatment or, in areas of new development, 75% removal of TSS and 'medium' metals removal." "Extensive and high quality riparian planting (90% of stream length, 20m buffer width, diverse species composition)."
G	C+ Extensive and high quality riparian planting	"Projected additional dwelling numbers accommodated with a smaller impervious footprint." "Extensive and high quality riparian planting (90% of stream length, 20m buffer width, diverse species composition)."
H	E+ Extensive and high quality riparian planting	"Lower copper-yielding brake pads and lower-zinc yielding tyres." "Extensive and high quality riparian planting (90% of stream length, 20m buffer width, diverse species composition)."

Source: Moores et al. (2016) pp. 20 and 23

For the purpose of this assessment, to be able to compare the cost variation between different development scenarios, we looked at the results for a fixed level of mitigation (model G) in relation to each of the five development scenarios. Table 20 presents the predicted total life cycle costs of mitigation scenario 'G' using WSD plus extensive, high quality riparian planting. It shows, for each development scenario, the breakdown of the total costs by stormwater treatment, earthworks erosion and sediment control (ESC), stormwater quantity control and riparian management.

Under most scenarios, costs are predicted to be higher in the Oteha Stream sub-catchment than in the Lucas Stream sub-catchment, reflecting the greater overall expansive development in the former sub catchment. Oteha Stream is also a larger sub-catchment and has a higher proportion of its area occupied by urban development.

The brownfields development scenario (scenario 3), involves the smallest development footprint in the Lucas Stream sub-catchment ($21.8m) but relatively high mitigation costs ($42.9 m) in the Oteha Stream sub-catchment. This is because there is a relatively small area of industrial land use in Lucas Stream and most of the industrial land use that would be redeveloped under this scenario located in Oteha Stream.

Life cycle costs in both sub-catchments are predicted to be highest under scenario 4 because this is the scenario which involves widespread greenfield, low density development across both sub-catchments. This also reflects the fact that under scenarios 1, 2 and 3 the sub-catchments are already partially developed (and partially mitigated) as a result of historic development. In contrast, scenarios 4 and 5 solely involve greenfield development and any mitigation applies to the full extent of the development footprint. In addition, a higher cost is associated with lower density (scenario 4) compared to higher density (scenario 5).

Table 20. Predicted life cycle costs ($ millions) of mitigation for urban development scenarios, Lucas Stream and Oteha stream sub-catchments. Costs are estimated over 50 years using a discount rate of 8 per cent

Scenario	Stormwater treatment		Earth works ESC		Stormwater quality control		Riparian management		Total	
	Lucas	Oteha	Lucas	Oteha	Lucas	Oteha	Lucas	Oteha	Lucas	Oteha
No development	0.4	1.1	0.0	0.0	0.4	1.0	0.0	0.0	0.8	2.1
1G	36.1	36.0	5.5	4.2	2.1	2.5	7.8	17.3	51.4	60.0
2G	32.8	31.8	6.9	7.4	1.9	2.3	7.8	17.3	49.4	58.8
3G	18.1	30.7	2.6	10.0	1.1	2.2	7.8	17.3	29.6	60.3
4G	83.6	160.8	14.0	20.8	4.3	8.0	14.5	17.3	116.4	207.0
5G	72.4	146.3	12.1	18.9	3.8	7.3	14.5	17.3	102.8	189.9

Land development: 1) Historic + low density 2) Historic + high density 3) Historic + brownfield 4) Greenfield low density 5) Greenfield high density
Mitigation: G) Best practice contaminant controls with Water Sensitive Design+ riparian planting
Source: Moores et al. (2016)

Figure 8 shows the population distribution in the ART3 units that are (at least partly) located in the Lucas Greek catchment. The figure indicates different population densities under the urban form scenarios in each part of the catchment. In addition, Table 21 shows housing development for approximately 22,900, 22,100 and 21,500 households corresponding to baseline (I9), intensive and expansive scenarios respectively. These changes would intensify the already developed outer areas of Auckland.

Figure 8. The population distribution in Lucas Creek catchment under the urban form scenarios

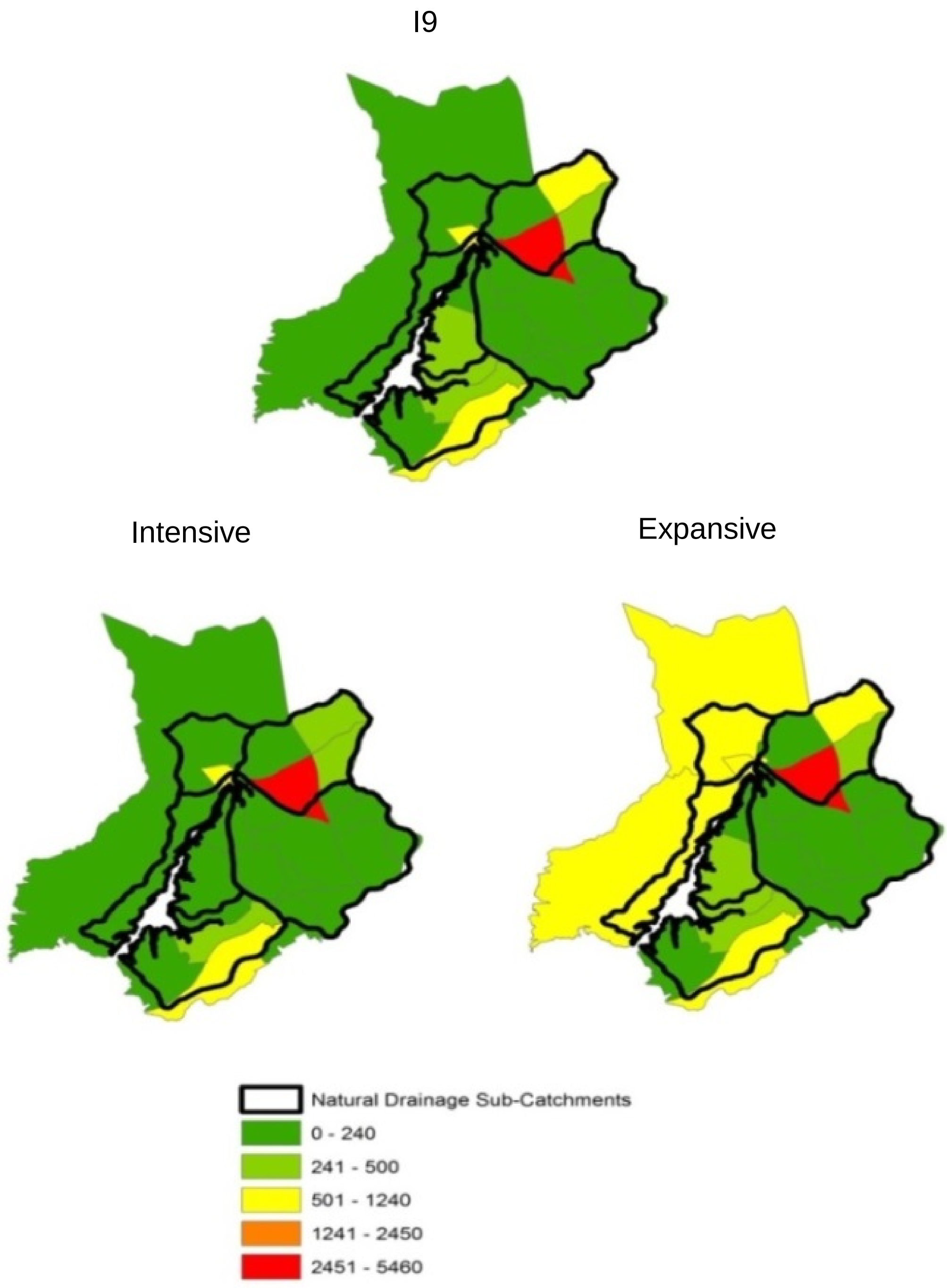


Table 21. Households' projection for ART3 zones overlapped with Lucas Creek catchment area under each of the urban form scenarios

Area	I9	Intensive	Expansive	I9	Intensive	Expansive
Industrial	1,616	1,615	1,520	7%	7%	7%
Outer 1	6,280	6,558	4,501	27%	30%	21%
Outer 2	6,643	6,338	6,768	29%	29%	31%
Outer 3	7,594	6,960	7,924	34%	31%	37%
Rural	789	681	876	3%	3%	4%
Total	**22,922**	**22,150**	**21,589**	**100%**	**100%**	**100%**

In summary:

- The life cycle cost would be lower in sub-catchments that are already partially developed (and partially mitigated) compared with the cost incurred in greenfield development.
- A higher life cycle cost could be associated with lower density greenfield development compared to higher density greenfield.

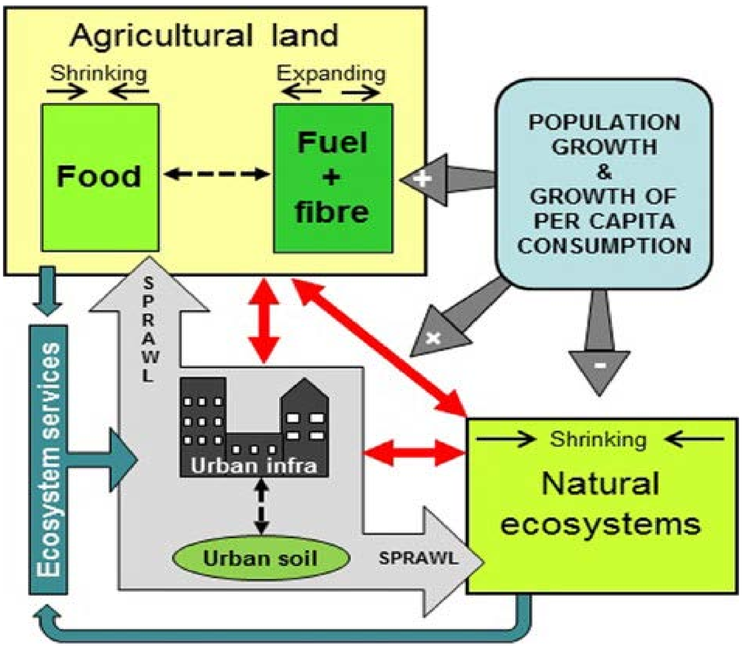
4.0 Soils

Soils are 'natural capital' and an asset to be maintained and protected so they can continue to support a variety of land use options in the future. The Auckland region 'overshoots' its useful land area by about a factor of three, which means it is not ecologically self-sufficient and depends on other regions and overseas (Smith and McDonald, 2008). High quality land and soils are valuable and non-renewable resources. They are a source of various ecosystem services including food, timber, and recreational and tourism opportunities, and have important cultural and historic value (Auckland Council, 2015). The continuous expansion of urban areas and land use changes could potentially contribute to environmental burdens in other sectors, including the agriculture and recreational sectors (Low, Choy and Buxton, 2013).

> *"Our agricultural, horticultural, and forestry industries, which all make a major contribution to our economy and support our way of life, depend largely on land. Our land environment also provides the habitat for many of our indigenous plants and animals – many of which exist nowhere else on Earth. Land provides food and materials, such as timber, and supports ecosystem services, such as the filtering of water." Ministry for the Environment and Statistics New Zealand (2015).*

The impact of expanding cities as the population continues to grow will increase the demand of agricultural land to be transferred to residential and industrial land despite the increase in the per capita consumption of resources. This conflict in land use often affects various ecosystem services (Curran-Cournane et al., 2016, Curran-Cournane et al., 2014) . Figure 9 illustrates the impact of expansive growth on agricultural land and ecosystem services.

Figure 9. The impact of sprawl development on soil ecosystem services



Adapted from: Setala et al.(2014), p.4.

A spatial analysis by Curran-Cournane et al. (2014) indicated that 10,080 ha (8.1%) of Auckland's high class land[20] (land use capability classes 1-3) was converted to development through urban extension, from 1975 to 2012. Furthermore, and subsequent to the Auckland Unitary Plan decisions, future growth disproportionately encroaches on high class land with 86 per cent of Land Use Capability (LUC) [21] class 1, 69 per cent of class 2 and 82 per cent of class 3 remaining as a result of the rezoning of Future Urban Zones (FUZ), Rural Urban Boundary (RUB) and Countryside Living Zones (CLZ) (Appendix 1).

The Auckland Regional Council Genuine Progress Indicator report (GPI) (McDonald et al., 2009), estimated the cost of converting high class land to the built environment for the Auckland region. It measured the cumulative loss of ecosystem services from 1970 to 2006 which continues to exist. The result of a study from Canterbury by Sandhu et al. (2007) was used to quantify the economic value of conventional farm land.[22] Findings from McDonald et al. (2009) report the total cumulative loss of $96.1million to urbanisation in 2006, considering an $11,290 cost per each hectare loss.

This assessment transfers the result of the GPI (2009) and Sandhu (2007) to estimate the impact of development under each of the scenarios on agricultural land.

Methodology

The methodology of the GPI and the result of Sandhu (2007) were used to calculate the loss of agricultural land and to estimate the economic loss that would incur in each scenario. The key assumptions and calculation processes are as follows:

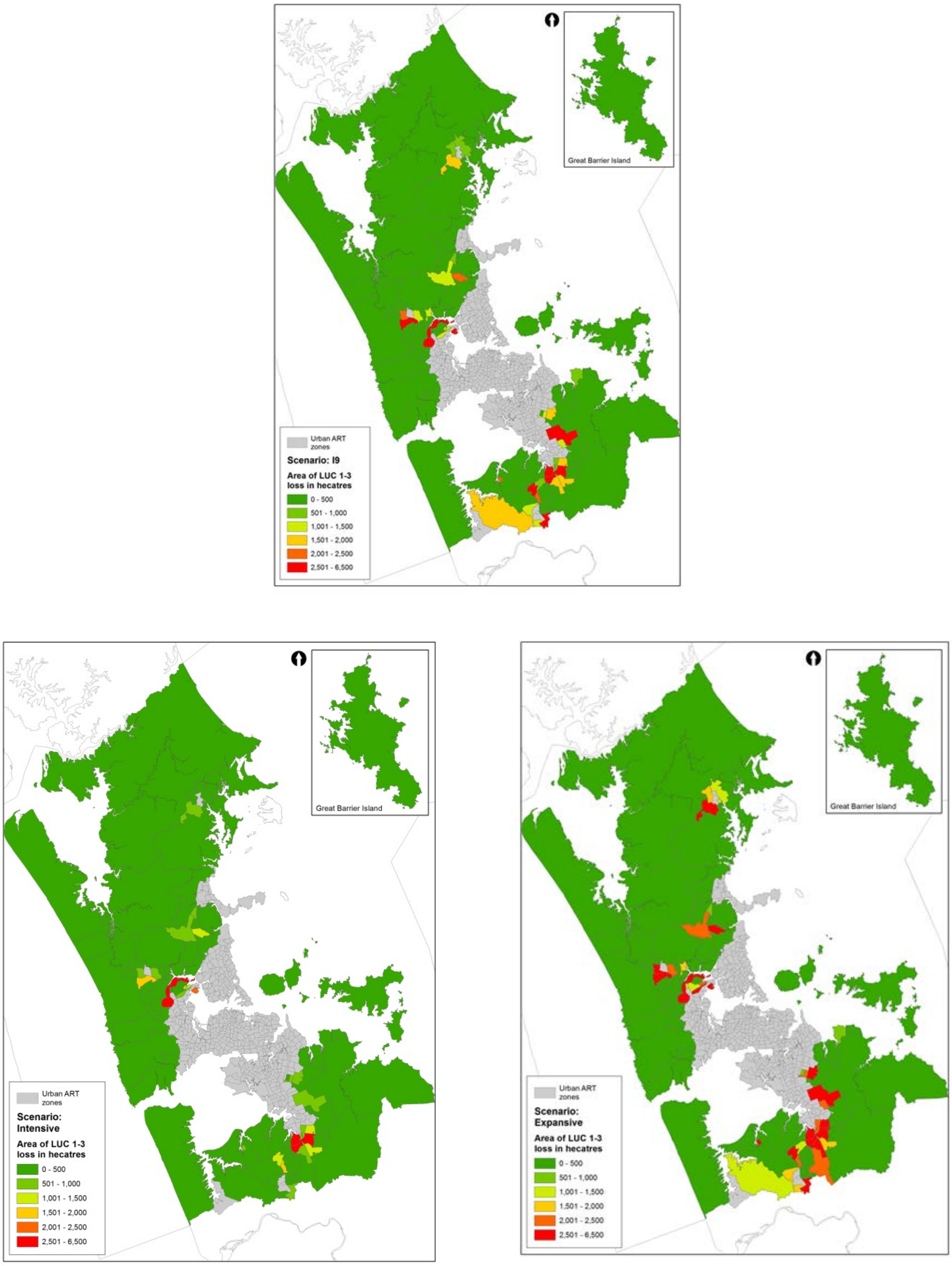
- The aim of this assessment is to compare the cost of soil loss of each urban form scenario. The soil loss is calculated for one year for each scenario and does not represent a cumulative cost.
- The 'rural' and 'FUZ' (including rural FUZ and urban FUZ) high class soils are the main potential losses of fertile land. Therefore, the fertile land that has already been under development in the 'inner' and 'outer' areas has not been considered as the loss as result of the urban form scenarios.
- The focus of this analysis concentrates on high class land. Land Use Capability (LUC) 1-3 are the main fertile lands that have been included in the loss calculation for each ART3 zone, rural or FUZ area. Land with lower capability also provides important ecosystem services have been excluded from the analysis. Figure 10 shows the changes to fertile soil as a consequence of each urban form scenario.

[20] According to the Auckland Unitary Plan, high class or elite land are defined as Land Use Capability (LUC) classes 1, 2 and 3, with negligible, slight or moderate, respectively, physical limitations for arable use.

[21] The land use capability (LUC) classification is systematic arrangement of different kinds of land according to those properties that determine its capacity for long-term sustained production, (Lynn et al., 2009).

[22] "The ecosystem services valued included biological control of pests, soil formation, mineralisation of plant nutrients, pollination, services provided by shelter belts and hedges, hydrological flows, aesthetics, carbon accumulation, nitrogen fixation, soil fertility, food, and raw materials." McDonald et al. (2009) p.47.

Figure 10. The geography of fertile soil loss based on each of the urban form scenarios



- The soil loss calculated using Equation 3, where SL_i is the soil loss in each ART3 zone i, ΔPD_a calculates changes in population density under urban form scenario a and $ALUC_j$ is the area of fertile land (LUC1-3) in each art zone.[23]

$$SL_i = \Delta PD_a \times \sum_{j=1}^{3} ALUC_j \qquad \text{Equation 1}$$

The result of the high quality agricultural land loss under each of the development scenarios is shown in Table 22.

Table 22. Estimated fertile soil loss (hectare) under each urban form scenario in 2046

ART3 zone		I9	Intensive	Expansive
Rural	Soil loss ha	10,388	3,616	18,760
	Proportion of the total loss	13.2%	8.0%	16.6%
FUZ	Soil loss ha	32,719	28,236	38,650
	Proportion of the total loss	41.6%	62.5%	34.3%
FUZ/Rural	Soil loss ha	23,088	7,411	34,613
	Proportion of the total loss	29.4%	16.4%	30.7%
FUZ/Urban	Soil loss ha	12,365	5,904	20,823
	Proportion of the total loss	15.7%	13.1%	18.5%
Total	**Soil loss ha**	**78,560**	**45,167**	**112,846**
	Proportion of the total loss	**100%**	**100%**	**100%**

- Sandhu et al. (2007) estimated the cost of soil loss between $1,792/ha/yr and $20,254/ha/yr in 2005 dollars. McDonald et al. (2009) used an average of NZD 2005 11,023/ha/yr, or NZD 2006 11, 290/ha/yr, to estimate the cost of urbanisation on high class soil in the Auckland region. Following McDonald et al. (2009), the cost of soil loss in 2017 dollars is estimated $14,052 per hectare, per year.[24]

The result of the fertile soil loss in 2046 as a result of each of the urban form scenarios shows that the loss under the expansive and base scenario is 2.5 times and 1.7 times greater than the intensive scenario respectively (see Table 23).

[23] It is assumed that the additional population would have normal distribution in each ART3 zone.
[24] Calculated using the inflation calculation tool available at: http://www.rbnz.govt.nz/monetary-policy/inflation-calculator

Table 23. Fertile soil cost under each urban form scenarios in 2046 $million (NZD 2017)

The urban form scenarios	Rural	FUZ	FUZ/Rural	FUZ/Urban	Total
I9	$146.0	$442.7	$312.4	$167.3	**$1,063.1**
Intensive	$48.9	$382.1	$100.3	$79.9	**$611.2**
Expansive	$253.9	$523.0	$468.4	$281.8	**$1,527.0**

In summary:

- The estimated fertile soil loss under the expansive scenario (112,846 hectare) would be 2.5 and 1.7 times greater than intensive and baseline scenarios.
- The area identified as FUZ would comprise the greatest proportion of the soil loss under all scenarios, following by FUZ/Rural.
- The total cost of fertile soil loss in 2046 would be lower for the intensive scenario at $611.2 million than the baseline (I9) scenario at $1,063.3 million. Both would be lower than the expansive scenario at $1,527.0 million.

5.0 Conclusions

The three different urban form scenarios are predicted to affect the natural environment differently. In this report we examined the impact of each of the scenarios on air quality, water bodies and fertile soils. The assessment was carried out at different levels of detail and with a mix of quantitative and qualitative analysis due to limitations in the available data and time constraints. The main purpose of this assessment was to compare the impact of scenarios; therefore the calculations were carried out for a single year 2046.

The key results of the analysis show that:

- Taking the higher carbon price (NZD 2017 $63.24/tonne CO_2), the total cost of transport emissions in 2046 estimated to be higher for the expansive scenario at $176.72 million than the intensive scenario at $174.56 million. Both will be possibly higher than the I9 (baseline) scenario at $174.28 million.
- The total cost of home heating emissions in 2046 could be higher for the expansive scenario at $123.35 million than the intensive scenario at $121.24 million and the baseline scenario at $122.35 million. The lowest damage costs are for the intensive scenario. This reflects the concentration of solid fuel heaters in the inner areas of the city and consequently potential replacement of more solid fuel burners with cleaner type of heaters as the result of development in these areas.
- The result of a case study on the impact of development on the Lucas Creek catchment shows that further development of water catchments that are already partly developed (i.e. they contain some level of mitigation of negative effects) may be more cost-effective than attempting to mitigate negative effects on water quality in greenfield catchments, hence favouring the intensive scenario.
- The result of our analysis based on the New Zealand literature shows fertile soil loss in 2046. The loss under expansive and base scenarios would be 2.5 times and 1.7 times greater than the intensive scenario respectively.
- In the absence of environmental mitigation the estimated cost of development on the environmental subsets (that have been monetised in this assessment) for the base and expansive scenarios i approximately 50 per cent and 100 per cent higher than intensive scenario respectively (see Table 24)

In light of the importance of sustainable development, there is a strong case for ongoing assessment of the impact of spatial planning on the natural environment and its related ecosystem services. This assessment is an indicative assessment rather than a full environmental assessment. A full environmental assessment is recommended.

Table 24. Summary of the estimated environmental costs, $million (NZD 2017), under the scenarios for 2046

Environment factor	Baseline (I9)	Intensive	Expansive
Local air quality (transport)	$60	$64	$55
Local air quality (home heating)	$122	$121	$123
Greenhouse gases	$114	$110	$122
Soils	$1,104	$635	$1,586
Total	**$1,401**	**$930**	**$1,886**

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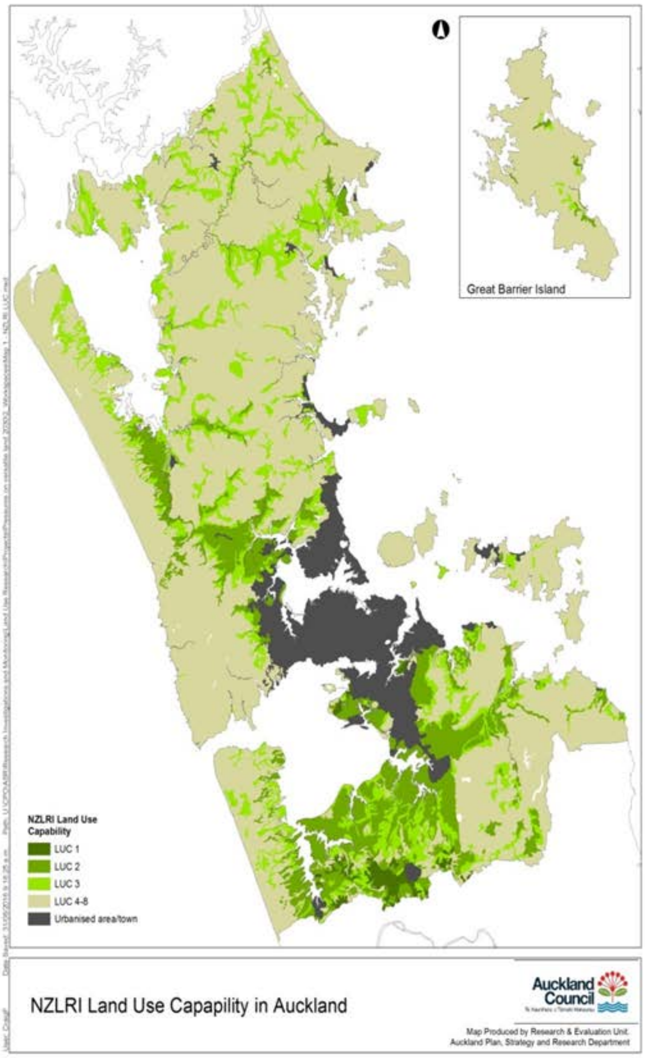
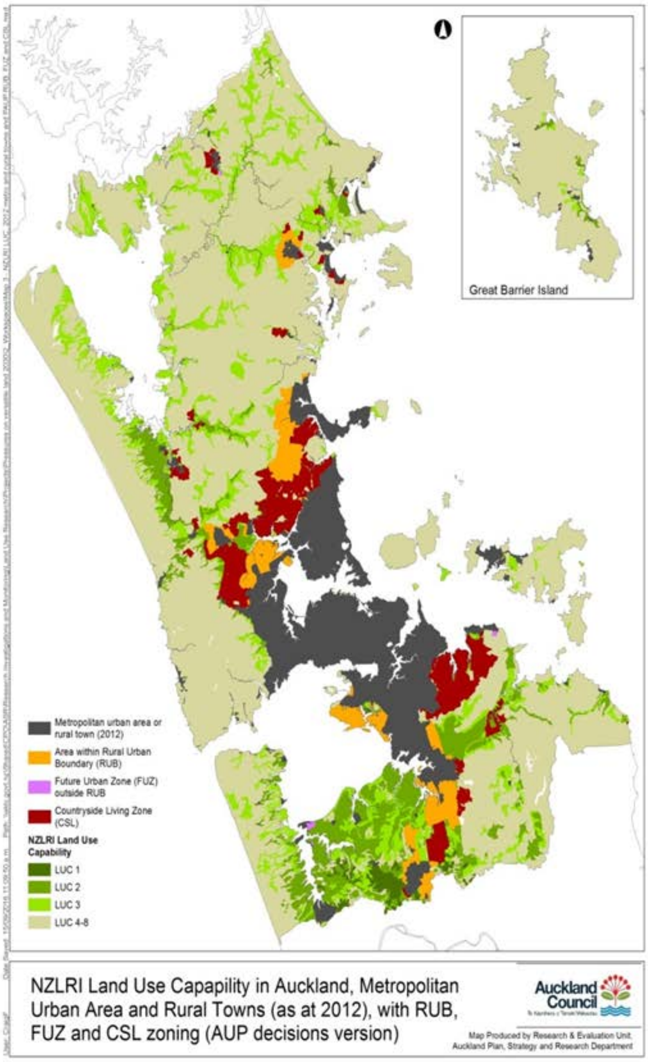
7.0 Appendix A: The Auckland Unitary Plan decisions, future growth disproportionately encroached on high class land





8.0 Appendix B: Glossary of terms

Environmental mitigations is one of the terms used in RMA as a mechanism to be considered when it has been identified that a proposal may generate adverse effects. Adverse effects must be avoided, remedied or mitigated irrespective of the benefits of the proposal.

Externalities are consequences of an economic activity experienced by unrelated third parties; it can be either positive or negative.

Greenhouse gases or climate pollutants cause global warming and impact globally e.g. carbon dioxide (CO2), black carbon (BC) and methane (CH4).

Harmful air pollutants cause adverse health effects and impact locally e.g. particulate matter (PM10 and PM2.5), nitrogen dioxide (NO2), carbon monoxide (CO), sulphur dioxide (SO2), and hydrocarbons (HCs).

Life-cycle costing or assessment (LCC or LCA) means considering all the costs that will be incurred during the lifetime of the product, work or service.

Negative spill overs in this report means negative externalities.

Social cost, damage cost or cost here means the cost of environmental degradation as the result of the scenarios. It could include the cost associated with impact on human health and/or forgone ecosystem services.

Social cost saving here means a decrease in the social cost associated with the local air emissions as the result of number of woodburners reduced.

Spatial policy means planning methods and approaches undertaken to influence the future distribution of land use activities within a defined area (at a range of geographic scales).

Find out more: phone 09 301 0101, email
rimu@aucklandcouncil.govt.nz or visit
aucklandcouncil.govt.nz and knowledgeauckland.org.nz