

Land cover in the Waikato region, 1996-2018

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Table of Contents

Executive summary	vi
1 Introduction	1
2 Methods and materials	3
2.1 Data source	3
2.2 Spatial and data analysis	3
2.2.1 Calculation of current state	3
2.2.2 Calculation of change over time	3
2.2.3 Data limitations	3
2.3 Category design	4
2.3.1 Land cover classes	4
2.3.2 Land use classes	5
3 Results and discussion	6
3.1 Regional picture	6
3.1.1 Current state	6
3.1.2 Change over time	8
3.2 Catchment management zone picture	14
3.2.1 Current state	14
3.2.2 Change over time	15
3.3 Land cover as a proxy for land use	21
3.3.1 Regional picture	21
3.3.2 Catchment management zone picture	24
4 Summary	26
4.1 Land cover	26
4.1.1 Regional picture	26
4.1.2 Catchment management zone picture	26
4.2 Land cover as a proxy for land use	26
4.2.1 Regional picture	26
4.2.2 Catchment management zone picture	27
5 Conclusions and recommendations	28
References	29
Appendices	31

Figures

- Figure 1. Proportion (%) of regional area occupied by broad land cover classes at the 2018 time-step (the current state). Area (ha) values for each class are presented. Regional land area is 2,466,629 ha. 6
- Figure 2. Map showing the distribution of the broad land cover classes across the Waikato region as at the 2018 time-step. The broad classes are the same as those for which maps can be viewed for the 1996 and 2018 time-steps on the LAWA website (www.lawa.org.nz/explore-data/land-cover). 7
- Figure 3. Net change in the land area occupied by broad land cover classes between individual time-steps (1996-2001, 2001-2008, 2008-2012, and 2012-2018) and across the entire monitoring period (1996-2018). Classes with positive area-change values had a net increase in area during the respective time-steps, whereas classes with negative area-change values had a net decrease in area. 9
- Figure 4. Changes in land area to and from the Forest class between individual time-steps (1996-2001, 2001-2008, 2008-2012, and 2012-2018) and across the entire monitoring period (1996-2018). Positive area-change values reflect an increase in (and movement to)

- Forest area during the respective time-steps, whereas negative area-change values reflect a decrease in (and movement from) Forest area. 10
- Figure 5. Changes in land area to and from the Grassland/other herbaceous vegetation class between individual time-steps (1996-2001, 2001-2008, 2008-2012, and 2012-2018) and across the entire monitoring period (1996-2018). Positive area-change values reflect an increase in (and movement to) Grassland/other herbaceous vegetation area during the respective time-steps, whereas negative area-change values reflect a decrease in (and movement from) Grassland/other herbaceous vegetation area. 11
- Figure 6. Changes in land area to and from the Urban/bare/lightly vegetated surfaces class between individual time-steps (1996-2001, 2001-2008, 2008-2012, and 2012-2018) and across the entire monitoring period (1996-2018). Positive area-change values reflect an increase in (and movement to) Urban/bare/lightly vegetated surfaces area during the respective time-steps, whereas negative area-change values reflect a decrease in (and movement from) Urban/bare/lightly vegetated surfaces area. 12
- Figure 7. Changes in land area to and from the Scrub/shrubland class between individual time-steps (1996-2001, 2001-2008, 2008-2012, and 2012-2018) and across the entire monitoring period (1996-2018). Positive area-change values reflect an increase in (and movement to) Scrub/shrubland area during the respective time-steps, whereas negative area-change values reflect a decrease in (and movement from) Scrub/shrubland area. 13
- Figure 8. Changes in land area to and from the Cropland class between individual time-steps (1996-2001, 2001-2008, 2008-2012, and 2012-2018) and across the entire monitoring period (1996-2018). Positive area-change values reflect an increase in (and movement to) Cropland area during the respective time-steps, whereas negative area-change values reflect a decrease in (and movement from) Cropland area. 13
- Figure 9. Proportion (%) of catchment management zone area occupied by broad land cover classes at the 2018 time-step (the current state). 14
- Figure 10. Net change in the land area occupied by broad land cover classes across the entire monitoring period (1996-2018) for each catchment management zone. Classes with positive area-change values had a net increase in area during the period, whereas classes with negative area-change values had a net decrease in area. 16
- Figure 11. Changes in land area to and from the Forest class across the entire monitoring period (1996-2018) for each catchment management zone. Positive area-change values reflect an increase in (and movement to) Forest area during the period, whereas negative area-change values reflect a decrease in (and movement from) Forest area. 18
- Figure 12. Changes in land area to and from the Grassland/other herbaceous vegetation class across the entire monitoring period (1996-2018) for each catchment management zone. Positive area-change values reflect an increase in (and movement to) Grassland/other herbaceous vegetation area during the period, whereas negative area-change values reflect a decrease in (and movement from) Grassland/other herbaceous vegetation area. 18
- Figure 13. Changes in land area to and from the Urban/bare/lightly vegetated surfaces class across the entire monitoring period (1996-2018) for each catchment management zone. Positive area-change values reflect an increase in (and movement to) Urban/bare/lightly vegetated surfaces area during the period, whereas negative area-change values reflect a decrease in (and movement from) Urban/bare/lightly vegetated surfaces area. 19
- Figure 14. Changes in land area to and from the Scrub/shrubland class across the entire monitoring period (1996-2018) for each catchment management zone. Positive area-change values reflect an increase in (and movement to) Scrub/shrubland area during the period, whereas negative area-change values reflect a decrease in (and movement from) Scrub/shrubland area. 20
- Figure 15. Changes in land area to and from the Cropland class across the entire monitoring period (1996-2018) for each catchment management zone. Positive area-change values reflect an increase in (and movement to) Cropland area during the period, whereas negative area-change values reflect a decrease in (and movement from) Cropland area. 20
- Figure 16. Proportion (%) of regional area occupied by land use classes at the 2018 time-step (the current state). Area (ha) values for each class are presented. Regional land area is 2,466,629 ha. 21

Figure 17. Map showing the distribution of the land use classes across the Waikato region as at the 2018 time-step.	22
Figure 18. Net change in the land area occupied by land use classes between individual time-steps (1996-2001, 2001-2008, 2008-2012, and 2012-2018) and across the entire monitoring period (1996-2018). Classes with positive area-change values had a net increase in area during the respective time-steps, whereas classes with negative area-change values had a net decrease in area.	23
Figure 19. Proportion (%) of catchment management zone area occupied by land use classes at the 2018 time-step (the current state).	24
Figure 20. Net change in the land area occupied by land use classes across the entire monitoring period (1996-2018) for each catchment management zone. Classes with positive area-change values had a net increase in area during the period, whereas classes with negative area-change values had a net decrease in area.	25

Tables

Table 1. Hierarchy of land cover classes used in the description of land cover state and trend.	4
Table 2. Hierarchy of land use classes used in the description of land use state and trend as they relate to the detailed land cover classes that define them.	5
Table 3. Breakdown of broad land cover classes by medium-level classes showing the land area (ha), and proportion of regional land area (%), occupied by each medium level class at the 2018 time-step (the current state).	8
Table 4. Breakdown of broad land cover classes by medium-level classes showing the net change in land area (ha) occupied by each medium level class between individual time-steps (1996-2001, 2001-2008, 2008-2012, and 2012-2018) and across the entire monitoring period (1996-2018).	10
Table 5. Breakdown of broad land cover classes by medium-level classes showing the land area (ha) occupied by each medium level class at the 2018 time-step (the current state) for each catchment management zone.	15
Table 6. Breakdown of broad land cover classes by medium-level classes showing the net change in land area (ha) occupied by each medium level class across the entire monitoring period (1996-2018) for each catchment management zone.	17
Table A1-1. Description of the LCDB v5.0 classes (Source: Manaaki Whenua – Landcare Research, LCDB Classes At Version5 - LCDB Environment and Land GIS LRIS Portal (scinfo.org.nz))	31
Table A2-1. Broad land cover class area and area-change (ha) data for each time-step.	33
Table A2-2. Medium land cover class area and area-change (ha) data for each time-step.	34
Table A2-3. Detailed land cover class area and area-change (ha) data for each time-step.	35
Table A2-4. Area-change data (ha) to and from broad land cover classes.	37
Table A2-5. Land use class area and area-change (ha) data for each time-step.	39
Table A3-1. Broad land cover class area and area-change (ha) data for each time-step.	40
Table A3-2. Medium land cover class area and area-change (ha) data for each time-step.	43
Table A3-3. Area-change data (ha) to and from broad land cover classes across the entire monitoring period (1996-2018) by catchment management zone.	47
Table A3-4. Land use class area and area-change (ha) data for each time-step.	49

Abstract

The Waikato region currently has a land cover profile that is dominated by Exotic grassland, indicative of a land use profile dominated by pastoral grazing. The major land cover/use change that has occurred in the region over the monitoring period (1996-2018) has been the net deforestation resulting from the large-scale 'pine to pasture conversion' that has occurred since 2001, primarily in the Upper Waikato zone. Land cover/use profiles vary by catchment management zone across the region, with those of the Lake Taupo and Coromandel zones being substantially different to those of the other zones (having higher proportions of Forest cover). Also, the Upper Waikato zone differed substantially from other zones in terms of the magnitude and direction of land cover/use change (i.e. the large-scale 'pine to pasture conversion'). The expansion of Cropping/horticulture mainly occurred between 1996 and 2008 and has subsequently slowed. Urban area has expanded throughout the monitoring period, but the magnitude of increases was variable following the substantial increases observed between 1996 and 2008. The land cover/use changes observed, particularly the net increases in the areas of Pastoral grazing, Urban area, and Cropping/horticulture, are indicative of an overall trend of land use intensification in the region over the monitoring period (but particularly since 2001). Although land cover data can provide a useful high-level proxy for land use, it cannot differentiate between types of pastoral grazing use (i.e. between dairying and drystock grazing).

Executive summary

This report describes the current state (as at 2018) and trends (change over time) in land cover for the Waikato region between 1996 and 2018. Data are presented for the region as a whole and by catchment management zone. Net changes in areas occupied by the land cover classes are presented but we also look beyond net change to report the area change to and from several key land cover classes over time. A regrouping of detailed land cover classes into classes more reflective of the use of the land (i.e. land use classes) was also undertaken to provide a high-level proxy for land use state and trend across the region and by catchment management zone.

The land cover of the Waikato region is currently dominated by Exotic grassland cover (at 53% of regional area). There is also a substantial area (34%) of Forest cover (comprising both Indigenous and Exotic forest covers, although Indigenous forest predominates). Also of note is that Scrub/shrubland occupies about 5% of regional area.

Over the monitoring period, net deforestation (i.e. a net decrease in Exotic forest area) and a net decrease in the area of Scrub/shrubland has occurred. Deforestation occurred between 2001 and 2018, with the reverse trend (i.e. net afforestation) apparent between 1996 and 2001. Most of the area lost from Exotic forest became Exotic grassland. This change has often been referred to as 'pine to pasture conversion'. The area lost from Scrub/shrubland was evenly split between Grassland/other herbaceous vegetation and Forest. In contrast to Exotic forest and Scrub/shrubland, net increases in the areas under Exotic grassland, Urban area, and Cropland occurred over the monitoring period. Much of the net increases in the areas of Cropland and Urban area occurred between 1996 and 2008, although the increase in Urban area continued after 2008 at a lesser rate. Most of the gains in the areas of Cropland and Urban area came from Exotic grassland cover.

There is considerable variation in land cover profiles across the region. Most catchment management zones have profiles dominated by Exotic grassland cover. However, the Lake Taupo and Coromandel zones have profiles dominated by Forest (particularly Indigenous forest) and Scrub/Shrubland covers. Cropland cover is relatively more prominent in the Central and Lower Waikato zones. The land cover profile of the Central Waikato Zone also includes a relatively high proportion of Urban area.

In contrast to the regional picture, net afforestation occurred in most catchment management zones over the monitoring period. However, these changes are overwhelmingly overshadowed by the large net deforestation that occurred in the Upper Waikato zone over the same period. This net deforestation reflects the large-scale 'pine to pasture conversion' that has occurred in the Upper Waikato since 2001. Consistent with the regional picture, the gains and losses in areas of land cover classes were dominated by shifts between Exotic Forest and Exotic grassland.

Current regional land use is dominated by pastoral grazing (other work has suggested that slightly more than 50% of the area of pastoral grazing in the region is used for dairying, with the remainder used for drystock grazing). Exotic forestry is also a significant land use type in the region (occupying about 12% of regional area). However, this area is substantially smaller than the area occupied by Indigenous cover (representing 28% of regional area). Cropping/horticulture is a relatively minor land use in the region on an area basis.

Net increases in Pastoral grazing, Cropping/horticulture, and Urban area over the monitoring period (1996-2018) were observed. Net decreases in Exotic forestry and Indigenous cover (predominantly Indigenous forest) were also observed, the latter occurring mainly between 2001 and 2012. These changes are indicative of an overall trend of land use intensification in the region over this period.

There are substantial variations in the land use profiles across the region. In most zones the dominant land use type is Pastoral grazing. However, the Lake Taupo and Coromandel zones have substantial proportions of Indigenous cover as well as some exotic forestry (and relatively little pastoral grazing). The Upper Waikato zone has the largest proportion of Exotic forestry whereas the Central Waikato has the largest proportion of Urban area. The Central and Lower Waikato zones have the largest proportions of Cropping/horticulture in the region.

Over the monitoring period a net increase in Exotic forestry area was observed for most zones. However, these changes were overshadowed by the large-scale 'pine to pasture conversion' that has occurred in the Upper Waikato zone, resulting in a substantial net increase in pastoral grazing area in that zone (and for the region as a whole).

Based on the analysis of land cover (and land use) state and trend as presented and described above, we conclude that:

- The Waikato region currently has a land cover profile that is dominated by Exotic grassland and that this is indicative of a land use profile dominated by pastoral grazing.
- The major land cover/use change that has occurred in the region over the monitoring period (1996-2018) has been the net deforestation resulting from the large-scale 'pine to pasture conversion' that has occurred since 2001, primarily in the Upper Waikato zone.
- Land cover/use profiles vary by catchment management zone across the region, with those of the Lake Taupo and Coromandel zones being substantially different to those of the other zones (having higher proportions of Forest cover). Also, the Upper Waikato zone differed substantially from the other zones in terms of the magnitude and direction of land cover use change (i.e. the large-scale 'pine to pasture conversion').
- The expansion of Cropping/horticulture mainly occurred between 1996 and 2008 and has subsequently slowed.
- Urban area has expanded throughout the monitoring period, but the magnitude of increases was variable following the substantial increases observed between 1996 and 2008.
- The land cover/use changes observed, particularly the net increases in the areas of Pastoral grazing, Urban area, and Cropping/horticulture, are indicative of an overall trend of land use intensification in the region over the monitoring period (but particularly since 2001).
- Although land cover data can provide a useful high-level proxy for land use, it cannot differentiate between types of pastoral grazing use (i.e. between dairying and drystock grazing).

Recommendations for further work include:

- Indicators and maps of land cover, land use, land use intensification, and land fragmentation currently in use regionally (and nationally) make use of variable input data, time-steps, and classifications which makes alignment and interoperability difficult. This has highlighted a need for a common development framework for land resource information to support improved interoperability and interpretation of aligned indicators and map layers.
- The Waikato Regional Council (and region) would benefit from the development of a region-wide land use monitoring and mapping programme purpose-designed to support policy development, State of the Environment reporting, and various modelling platforms (e.g. the Waikato Regional Prioritisation Framework, etc.).

1 Introduction

The term 'land cover' relates to the types of vegetation and built or natural features that occur at (i.e. 'cover') the land's surface. Describing and monitoring land cover across the Waikato region and its constituent catchment management zones in a consistent and systematic way enables us to characterise our landscapes and identify significant changes in land cover and (to some extent) land use through time. Moreover, characterising the current state of land cover and understanding changes in that cover over time is important because the type and location of vegetation cover can influence land stability and the movement of water (including entrained sediment and nutrients) through the landscape (e.g. Glade, 2003; Kamarinas et al., 2016; Phillips et al., 2020).

Land cover is sometimes used as an indicative proxy to describe 'land use'. However, it is important to note that land cover is not exactly analogous to land use, although the two things are closely related, and the terms are sometimes used interchangeably. Land use describes the different ways that people use the land (e.g. dairy pastoral grazing or drystock pastoral grazing, etc.). Land cover can be influenced by land use. For example, a forestry use will likely have an exotic forest cover and a pastoral use will have an exotic grassland cover. On the other hand, the same land cover type may have multiple different land uses (e.g. the different types of pastoral land uses with an exotic grassland cover). The latter is the main limitation with using land cover as a proxy for land use – i.e. land cover cannot differentiate between dairy and drystock pastoral use. Nevertheless, changes to pastoral, cropping, or urban land cover areas, relative to the areas of forest/woody or other natural/indigenous cover types, can provide a general indication of changes in land use intensity. A significant shift from exotic forest/forestry to exotic grassland/pastoral grazing (primarily for dairying use and driven by economic factors) in the southern part of the region (upper Waikato) during the first decade of the twenty-first century has previously been recognised (Hawke, 2004; Cameron et al., 2009).

Land cover changes can affect water quality (Kamarinas et al., 2016). Woody vegetation cover (mainly forest and scrub/shrubland covers) provides extensive root systems which help to hold the soils on hillslopes in place. Also, where woody vegetation provides a closed canopy, the impact of heavy rainfall on hillslopes is lessened because the foliage and branches intercept the rainfall, preventing much of it from directly landing on the soil surface. This interception of rainfall has the effect of reducing surface water run-off from hillslopes which, in turn, helps prevent soil erosion and the loss of sediment and associated nutrients like phosphorus to waterways, lakes, and estuaries (e.g. Glade, 2003; Kamarinas et al., 2016; Phillips et al., 2020). Over time, landslides have made significant contributions to deposits of sediment to receiving environments such as lakes, estuaries, and coastal wetlands following deforestation (Glade, 2003). Kamarinas et al. (2016) looked at the impact of vegetation cover removal (exposing bare soil) on indicators of water quality between 2000 and 2013 using multitemporal datasets in the Hotoe River catchment (containing exotic forest and grassland covers). They found a relationship between trends in land disturbance and visual water clarity.

Dudley et al. (2020) looked at the impact of urban and agricultural land covers on estuarine water quality in New Zealand. They found that estuaries with catchments dominated by agricultural land cover had greater concentrations of total phosphorus whereas estuaries with more urban land cover had greater nutrient (e.g. nitrate and total phosphorus) and chlorophyll-*a* concentrations. They also found that turbidity was somewhat correlated with the proportion of agricultural covers in catchments. Auckland Council's monitoring of state and trend in river ecology has shown that, between 2010 and 2019, a pattern of declining stream ecological health as the degree of land cover modification or land use intensity increased, with streams under indigenous forest generally having the best ecological health and those in urban catchments the worst (Chaffe, 2021). In a national-level analysis of state and trends in the water quality of New Zealand rivers, Larned et al. (2016) found that the water quality of rivers under exotic forest and

natural land cover was better than that of rivers in urban and pastoral catchments. They showed that as the proportions of agricultural intensity and urban cover within catchments increased, several key indicators of water quality deteriorated (i.e. increased nutrient and *Escherichia coli* concentrations and decreased Macroinvertebrate Community Index scores and visual clarity).

Ecological (biodiversity) functions also have complex relationships with land cover. Some types of land cover (e.g. indigenous covers; tussock grassland, etc.), and their location and connectedness with landscapes are important in terms of the maintenance and enhancement of indigenous biodiversity and threatened environments, either in terms of their intrinsic values or as important habitats for other rare or endangered species. Area change in indigenous land cover based on the New Zealand Land Cover Database (LCDB) was examined nationally by Dymond et al. (2017) and they present a method for estimating uncertainty associated with area change for five key indigenous covers. Also, land cover information derived from two national databases (LCDB and Waters of National Importance) has recently been used by Dymond et al. (2021) to revise the 'current' spatial extent of freshwater wetlands in New Zealand. Several forest covers (natural beech forest, managed beech forest, and an exotic pine forest) were compared to exotic grassland (pasture) cover in terms of ground beetle (Carabidae) assemblages by Berndt and Brockerhoff (2019) in the Canterbury region. They found that the ground beetle assemblages of the forested covers were similar and that these were significantly different to the assemblages under pasture cover. In addition to the present work, Waikato Regional Council monitors the extent of indigenous vegetation and natural bare surfaces in the region that have some form of legal protection (e.g. reserves or covenants, etc.). That monitoring shows that, although the area of indigenous land cover (in private ownership) protected by QEII covenants has increased at a rate of 425 ha per year (on average) since 1996, more than 46,000 ha of indigenous cover in the most threatened land environments in the region currently have no legal protection (Denyer and Tait, 2022).

This report describes the current state (as at 2018) and trends (change over time) in land cover for the Waikato region between 1996 and 2018. Data are presented for the region as a whole and by catchment management zone. Net changes in areas occupied by the land cover classes are presented but we also look beyond net change to report the area change to and from several key land cover classes over time. A regrouping of detailed land cover classes into classes more reflective of the use of the land (i.e. land use classes) was also undertaken to provide a high-level proxy for land use state and trend across the region and by catchment management zone.

2 Methods and materials

2.1 Data source

All the data used in the analysis of state and trend in land cover and land use classes included in this report were derived from the Land Cover Database (LCDB) version 5.0, released in January 2020. The LCDB provides broadly consistent land cover maps nationally, derived from the analysis of satellite images, that show the spatial distribution of 34 'detailed' land cover classes for mainland New Zealand at a scale of approximately 1:50,000. LCDB v5.0 was created by Manaaki Whenua – Landcare Research and is made available for use under Creative Commons Attribution 4.0 International Licence (CC BY 4.0). Version 5.0 is the most recent iteration of the LCDB and encompasses five time-steps (or 'snapshots' in time): 1996, 2001, 2008, 2012, and 2018. Data for the 2018 time-step was derived mainly from satellite imagery collected over the summer period of 2018/19. It is important to note that the update of LCDB to version 5.0 involved the corrections to all previous time-steps in accordance with the latest mapping protocols and best available information, and not simply the addition of a new time-step. This 'backward compatibility' is important for examining trends in land cover change over time. More detailed information on LCDB is available online from the LRIS Portal.

2.2 Spatial and data analysis

The LCDB v5.0 data were classified according broad, medium, and detailed classes (as described in subsequent sections) overlain by regional and catchment management zone boundaries corresponding to the most recent (2018) time-step in a Geographic Information System (GIS) to derive the data for the Waikato region and for each of the eight catchment management zones within the region. Manifold version 9 was the GIS used for this analysis. Total regional and zone areas were also derived. The data relating to the land use classes represent a reclassification of the detailed land cover classes as described in subsequent sections.

2.2.1 Calculation of current state

The primary metric reported in this report is the area of land, expressed both in absolute (area value in hectares) and relative (proportion of regional or zone area) terms, occupied by each land cover (or land use) class at the most recent time-step (2018). The area data was generated via GIS analysis using Manifold version 9. Area values were also calculated for each of the four previous time-steps (i.e. 1996, 2001, 2008, and 2012) to enable the analysis of change over time (i.e. trends).

2.2.2 Calculation of change over time

Net change in the area occupied by the various land cover (and land use) classes between two time-steps (e.g. 1996-2001) was calculated by difference, with net increases presented as positive change values and net decreases as negative change values. Net change was examined for each period between the five time-steps (1996-2001, 2001-2008, 2008-2012, and 2012-2018) and across the entire monitoring period (1996-2018). However, net change alone tells us nothing about the sources or destinations (in terms of other classes) of the area gains and losses experienced by a particular land cover class over a given time-step (e.g. 2008-2012). Therefore, a GIS analysis (using Manifold version 9) was undertaken to determine the sources of area gains to, and the destinations of area losses from, (as well as the magnitude of the gains and losses) for each land cover class.

2.2.3 Data limitations

Note that the land cover data used in this analysis are at a regional scale. Also, note that the catchment management zone boundaries do not exactly match the regional boundary, particularly at the coastal margins. This means that, for some land cover/use classes, the sum of the catchment management zone areas may not exactly equate to the regional totals.

2.3 Category design

2.3.1 Land cover classes

The land cover classes used, including their hierarchical arrangement (Table 1), were designed specifically to describe the nature of the conditions (surface type or vegetation cover type) occurring at the land surface.

Table 1. Hierarchy of land cover classes used in the description of land cover state and trend.

Broad Classes	Medium Classes	Detailed Classes
Urban/bare/lightly-vegetated surfaces	Artificial bare surfaces	Transport infrastructure
		Surface mine or dump
	Natural bare/lightly-vegetated surfaces	Sand or gravel
		Landslide
		Gravel or rock
		Permanent snow and ice
		Alpine grass/herbfield
	Urban area	Built-up area (settlement)
		Urban parkland/open space
Cropland	Cropping/horticulture	Short-rotation cropland
		Orchards, vineyards or other perennial crops
Forest	Exotic forest	Forest - harvested
		Exotic forest
		Deciduous hardwoods
	Indigenous forest	Indigenous forest
		Broadleaved indigenous hardwoods
Grassland/other herbaceous vegetation	Exotic grassland	Depleted grassland
		High producing exotic grassland
		Low producing grassland
	Other herbaceous vegetation	Herbaceous freshwater vegetation
		Flaxland
		Herbaceous saline vegetation
	Tussock grassland	Tall tussock grassland
Scrub/shrubland	Exotic scrub/shrubland	Gorse and/or Broom
		Mixed exotic shrubland
	Indigenous scrub/shrubland	Manuka and/or Kanuka
		Matagouri or Grey scrub
		Fernland
		Sub-alpine shrubland
Mangrove		
Water bodies	Water bodies	Lake or pond
		River
		Estuarine open water
		Not land

The classes were originally developed by the EMaR (Environmental Monitoring and Reporting) Land Project for the purposes of national and regional land cover reporting on the Land, Air, Water (LAWA) website. They were subsequently adopted by the Ministry for the Environment and Stats NZ for use in national domain reporting (e.g. for the 'Our Land 2018' report – Ministry for the Environment and Stats NZ, 2021). However, for the 'Our Land 2021' report, they separated the medium-level classes into three indicator groups; exotic land cover, indigenous land cover, and urban land cover and included the two Chatham Islands-specific detailed classes

(Dune shrublands and Peat shrublands) within the definition of the ‘Indigenous scrub/shrubland’ medium-level class (Ministry for the Environment and Stats NZ, 2021). Although, the relationships between the detailed and medium-level classes were otherwise the same as those used in LAWA and in this report. The detailed classes listed in Table 1 are fully described in Thompson et al. (2003). A summary of descriptions for each of the detailed classes are reproduced in Appendix 1 (Table A1).

2.3.2 Land use classes

The detailed land cover classes were regrouped into classes more reflective of the use of the land (Table 2), as opposed to classes specifically designed to describe land cover. However, some of the land use classes (e.g. ‘Urban area’ and ‘Cropping/horticulture’) are the same as the medium-level land cover classes (Table 1).

Table 2. Hierarchy of land use classes used in the description of land use state and trend as they relate to the detailed land cover classes that define them.

Land Use Classes	Detailed Classes
Transport/other infrastructure	Transport infrastructure
	Surface mine or dump
Urban area	Built-up area (settlement)
	Urban parkland/open space
Cropping/horticulture	Short-rotation cropland
	Orchards, vineyards or other perennial crops
Exotic forestry	Forest - harvested
	Exotic forest
Other exotic vegetation	Gorse and/or Broom
	Mixed exotic shrubland
	Deciduous hardwoods
Pastoral grazing	Depleted grassland
	High producing exotic grassland
	Low producing grassland
Indigenous land cover	Sand or gravel
	Landslide
	Gravel or rock
	Permanent snow and ice
	Alpine grass/herbfield
	Indigenous forest
	Broadleaved indigenous hardwoods
	Manuka and/or Kanuka
	Matagouri or Grey scrub
	Fernland
	Sub-alpine shrubland
	Mangrove
	Herbaceous freshwater vegetation
	Flaxland
	Herbaceous saline vegetation
Tall tussock grassland	
Water bodies	Lake or pond
	River
	Estuarine open water
	Not land

3 Results and discussion

3.1 Regional picture

3.1.1 Current state

The current state of land cover in the Waikato region, reflected in the proportion of regional area (2,466,629 ha) occupied by the broad-level land cover classes as at the 2018 time-step, is presented in Figure 1. Land cover in the region is dominated by Grassland/other herbaceous vegetation and Forest covers, representing 54% and 34% of regional area, respectively. Scrub/shrubland cover occupies 5% of regional area, whereas Urban/bare/lightly-vegetated surfaces and Cropland comprise only 2% and 1%, respectively.

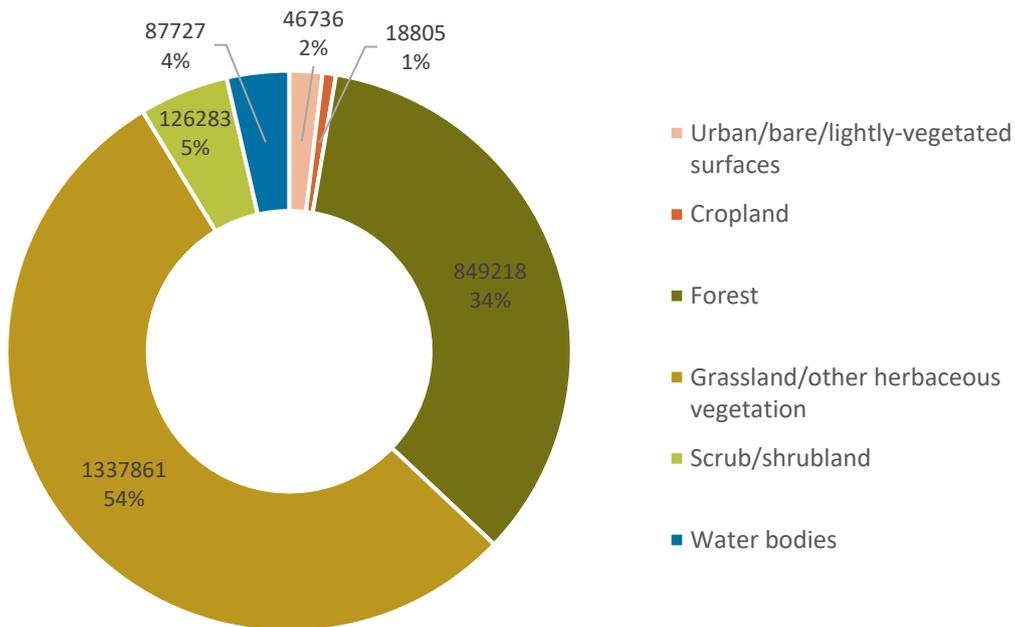


Figure 1. Proportion (%) of regional area occupied by broad land cover classes at the 2018 time-step (the current state). Area (ha) values for each class are presented. Regional land area is 2,466,629 ha.

The distribution of the broad classes across the Waikato region in 2018 is shown in Figure 2. Forest and Scrub/shrubland covers tend to be more prevalent in the north-eastern, western, and south-eastern parts of the region, particularly where the terrain is steeper.

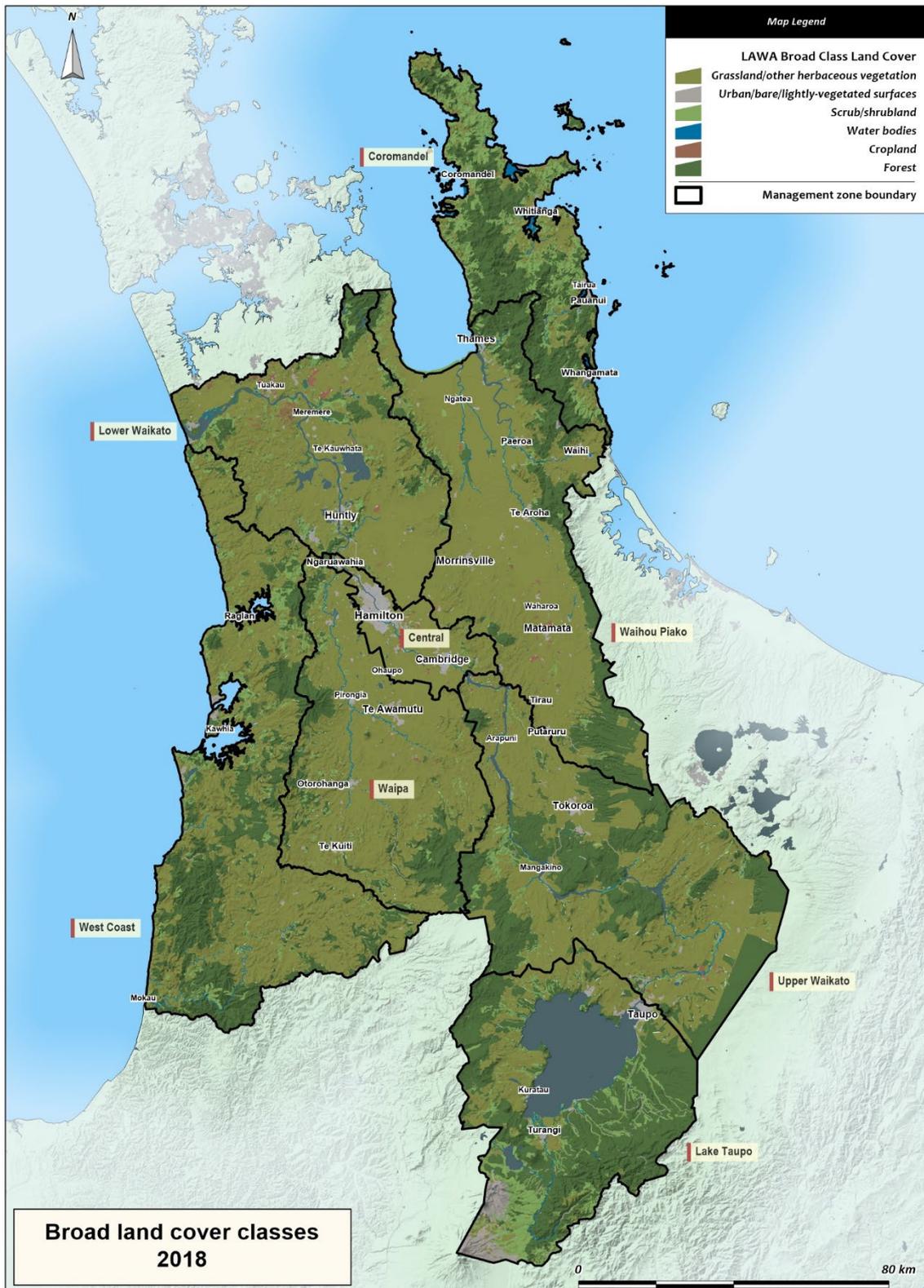


Figure 2. Map showing the distribution of the broad land cover classes across the Waikato region as at the 2018 time-step. The broad classes are the same as those for which maps can be viewed for the 1996 and 2018 time-steps on the LAWA website (www.lawa.org.nz/explore-data/land-cover).

To provide a greater understanding of the land cover ‘profile’ of the Waikato region, a breakdown of the composition of the broad land cover classes in terms of their constituent medium-level classes is provided in Table 3. These data show that Grassland/other herbaceous vegetation is predominantly comprised of Exotic grassland (largely pasture) cover, which occupies 53% of regional area, with Tussock grassland and Other herbaceous vegetation (comprising flaxland and freshwater and saline herbaceous vegetation) covers accounting for 1% of regional area. Forest vegetation is comprised of both Indigenous and Exotic forest covers. Indigenous forest is dominant (accounting for 21% of regional area) but there is also a substantial area of Exotic forest (13% of regional area). Similarly, Scrub/shrubland is dominated by Indigenous scrub/shrubland (4.62% of regional area, rounded to 5%), with Exotic scrub/shrubland occupying 0.50% of regional area (rounded 1%). Urban/bare/lightly vegetated surfaces are predominantly comprised of Urban area (28,394 ha) but also include a substantial area of Natural bare/lightly-vegetated surfaces (14, 315 ha) and a smaller area of Artificial bare surfaces (4,028 ha).

Table 3. Breakdown of broad land cover classes by medium-level classes showing the land area (ha), and proportion of regional land area (%), occupied by each medium level class at the 2018 time-step (the current state).

Broad Classes	Medium Classes	2018 Area (ha)	Proportion of regional area (%)
Urban/bare/lightly-vegetated surfaces	Artificial bare surfaces	4028	<1
	Natural bare/lightly-vegetated surfaces	14315	1
	Urban area	28394	1
Cropland	Cropping/horticulture	18805	1
Forest	Exotic forest	322667	13
	Indigenous forest	526551	21
Grassland/other herbaceous vegetation	Exotic grassland	1307586	53
	Other herbaceous vegetation	22313	1
	Tussock grassland	7962	<1
Scrub/shrubland	Exotic scrub/shrubland	12446	1
	Indigenous scrub/shrubland	113836	5
Water bodies	Water bodies	87727	4

3.1.2 Change over time

The size of the land areas occupied by the broad land cover classes has changed over time, and for the Grassland/other herbaceous and Forest covers, the direction of change has also reversed since 2001 (Figure 3). The area-change data presented in Figure 3 reflects the net change that occurred during a particular time-step (e.g. 2008-2012). Most land cover classes tend to both gain and lose area between one time-step and another as the cover at individual land parcels changes to or from other classes. If the net change for a class is positive, that class gained a larger area of land than it lost, and vice-versa if the net change is negative.

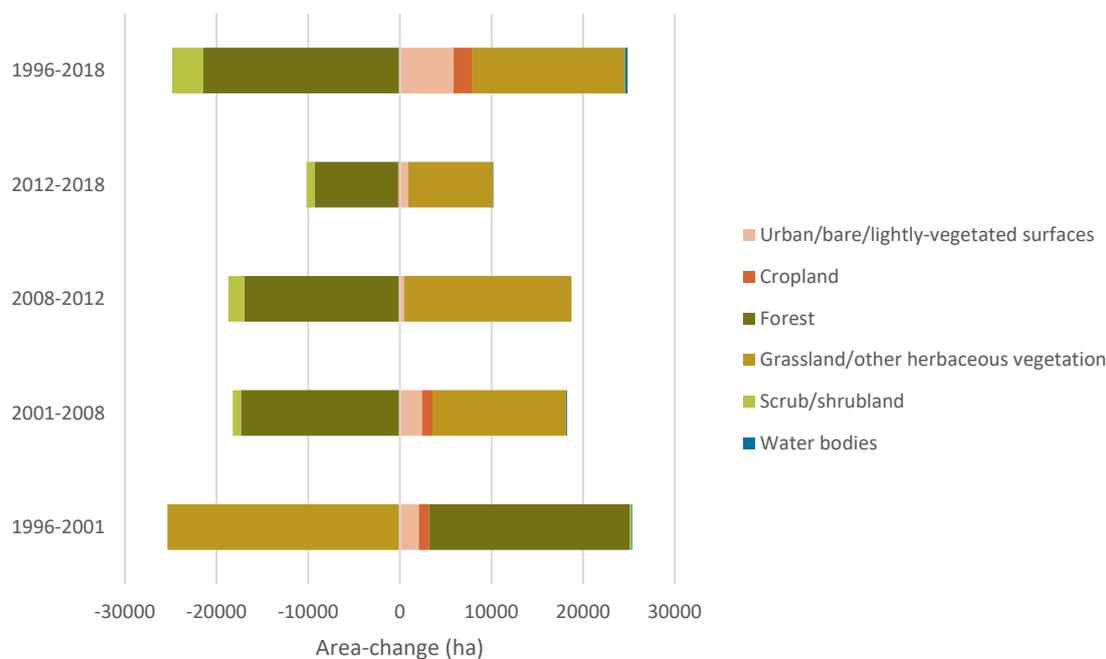


Figure 3. Net change in the land area occupied by broad land cover classes between individual time-steps (1996-2001, 2001-2008, 2008-2012, and 2012-2018) and across the entire monitoring period (1996-2018). Classes with positive area-change values had a net increase in area during the respective time-steps, whereas classes with negative area-change values had a net decrease in area.

Between 1996 and 2001, the area occupied by Grassland/other herbaceous vegetation in the region decreased by more than 25,000 ha (net), whereas the area with Forest cover increased by almost 22,000 ha (net). However, this apparent ‘trend’ (apparent in that it is only reflected in one monitoring period) of afforestation reversed after 2001. During the three periods following 2001 (i.e. 2001-2008, 2008-2012, and 2012-2018) there were net increases in the area of Grassland/other herbaceous vegetation and net decreases in the area of Forest. The area occupied by Scrub/shrubland also showed a net decrease after 2001. There was a net increase in Urban/bare/lightly-vegetated surfaces during all periods but these increases were greatest in 1996-2001 and 2001-2008. Cropland area also increased during the 1996-2001 and 2001-2008 time-steps.

Net changes in class areas across the entire monitoring period (1996-2018) reflect the prevailing land cover change trends observed since 2001 (i.e. net decreases in the areas of Forest and Scrub/shrubland and net increases in the areas of Grassland/other herbaceous vegetation, Urban/bare/lightly-vegetated surfaces, and Cropland), but do mask the reversed ‘trend’ relating to Grassland/other herbaceous vegetation and Forest prior to 2001.

Table 4 provides a breakdown on net area changes at the medium land cover category level. These data show that much of the net changes observed in relation to the Urban/bare/lightly-vegetated surfaces, Forest, and Grassland/other herbaceous vegetation classes at the broad level (Figure 3) are due to net changes in Urban area, Exotic forest, and Exotic grassland. In contrast, the net change (decrease) in Scrub/shrubland between 1996-2018 was relatively evenly contributed to by Indigenous and Exotic scrub/shrubland.

Table 4. Breakdown of broad land cover classes by medium-level classes showing the net change in land area (ha) occupied by each medium level class between individual time-steps (1996-2001, 2001-2008, 2008-2012, and 2012-2018) and across the entire monitoring period (1996-2018).

Broad Classes	Medium Classes	Area-change (ha)				
		1996-2001	2001-2008	2008-2012	2012-2018	1996-2018
Urban/bare/lightly-vegetated surfaces	Artificial bare surfaces	311	493	150	-7	947
	Natural bare/lightly-vegetated surfaces	6	-31	5	98	78
	Urban area	1764	1968	310	803	4845
Cropland	Cropping/horticulture	1090	1134	-64	-186	1974
Forest	Exotic forest	22329	-17382	-17041	-9177	-21271
	Indigenous forest	-430	49	141	69	-170
Grassland/other herbaceous vegetation	Exotic grassland	-25023	14697	18261	9209	17145
	Other herbaceous vegetation	-331	-122	-11	2	-462
	Tussock grassland	0	0	0	45	45
Scrub/shrubland	Exotic scrub/shrubland	-519	-305	-543	-440	-1806
	Indigenous scrub/shrubland	690	-597	-1222	-470	-1600
Water bodies	Water bodies	112	96	13	55	276

Area change to and from Forest

Most of the area change to and from Forest cover over time has been from and to Grassland/other herbaceous vegetation (Figure 4). However, some of the gains in Forest area between 1996-2018 also came from Scrub/shrubland. Most of the area gain from Shrub/shrubland occurred during 1996-2001.

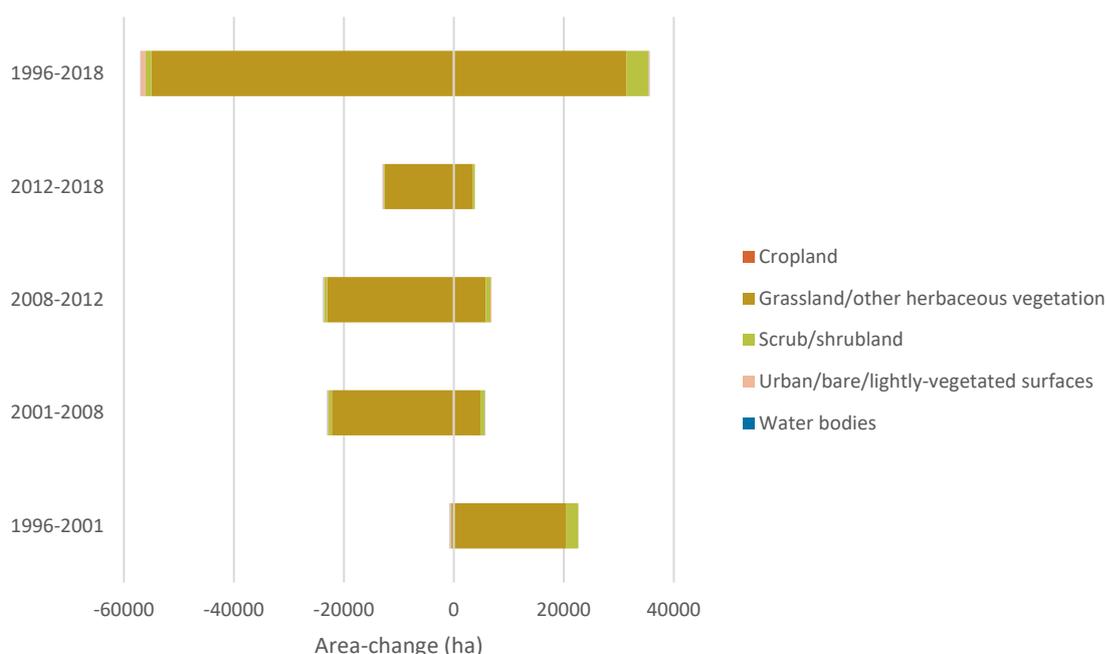


Figure 4. Changes in land area to and from the Forest class between individual time-steps (1996-2001, 2001-2008, 2008-2012, and 2012-2018) and across the entire monitoring period (1996-2018). Positive area-change values reflect an increase in (and movement to) Forest area during the respective time-steps, whereas negative area-change values reflect a decrease in (and movement from) Forest area.

Area change to and from Grassland/other herbaceous vegetation

Most of the area change to and from Grassland/other herbaceous vegetation over time has been from and to Forest cover (Figure 5). However, some of the area lost from Grassland/other herbaceous vegetation between 1996 and 2018 also went to Urban/bare/lightly-vegetated surfaces, Scrub/shrubland, and Cropland.

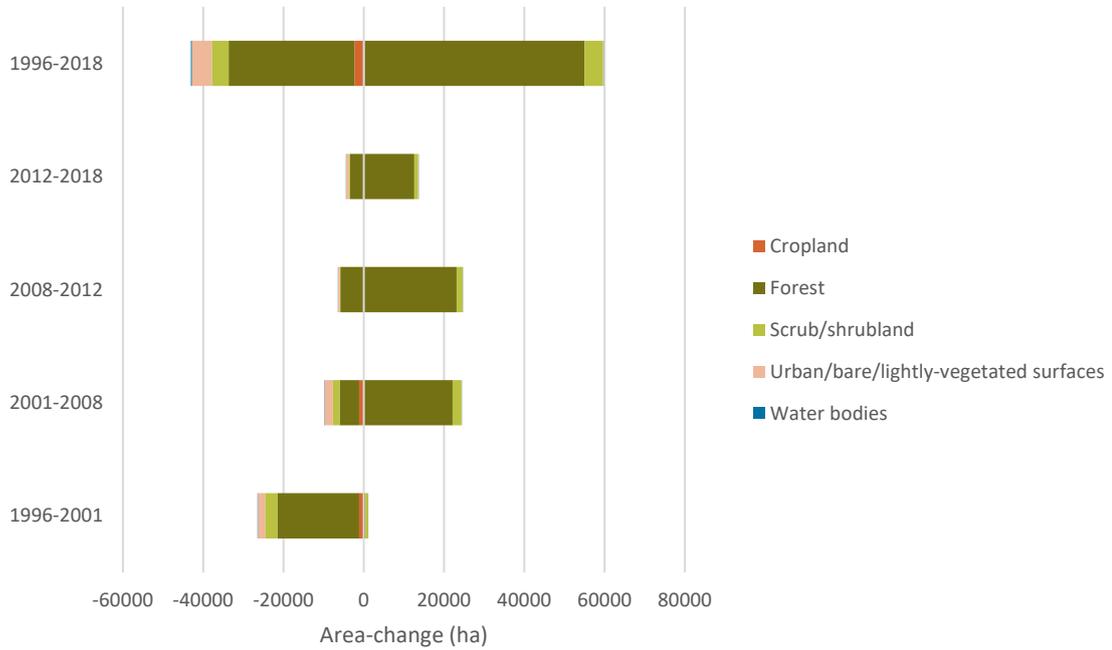


Figure 5. Changes in land area to and from the Grassland/other herbaceous vegetation class between individual time-steps (1996-2001, 2001-2008, 2008-2012, and 2012-2018) and across the entire monitoring period (1996-2018). Positive area-change values reflect an increase in (and movement to) Grassland/other herbaceous vegetation area during the respective time-steps, whereas negative area-change values reflect a decrease in (and movement from) Grassland/other herbaceous vegetation area.

Area change to and from Urban/bare/lightly vegetated surfaces

Over the monitoring period (1996-2018), Urban/bare/lightly-vegetated surfaces have largely gained area, with relatively little area lost to other land covers (Figure 6). Most of the area gained by Urban/bare/lightly-vegetated surfaces came from Grassland/other herbaceous vegetation, with contributions also coming from Forest, Cropland, and Scrub/shrubland.

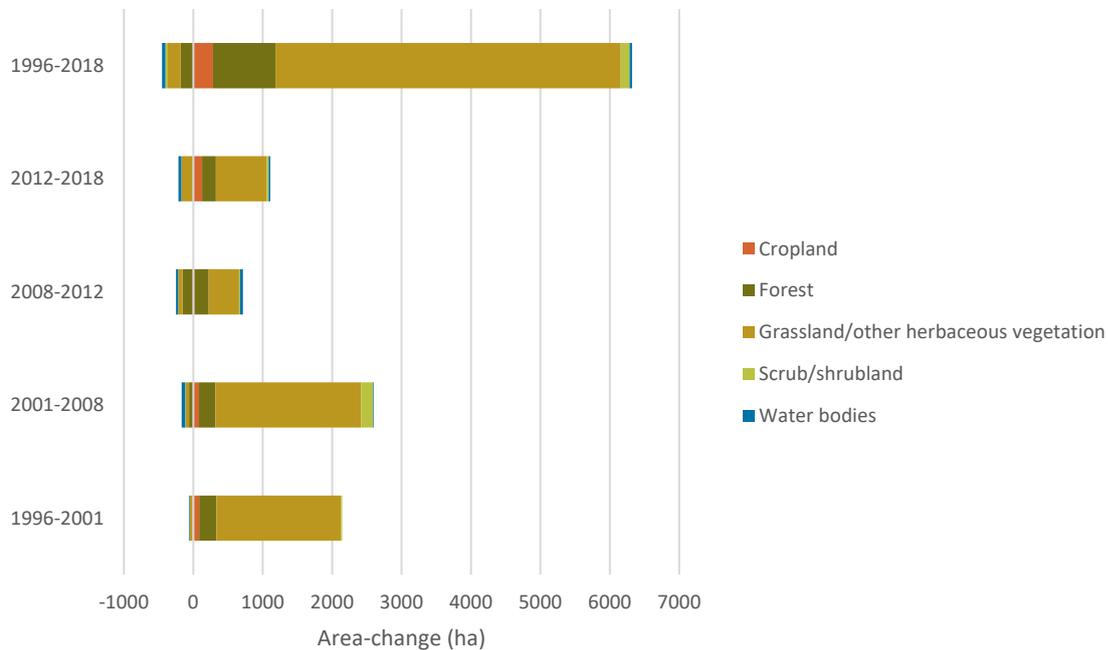


Figure 6. Changes in land area to and from the Urban/bare/lightly vegetated surfaces class between individual time-steps (1996-2001, 2001-2008, 2008-2012, and 2012-2018) and across the entire monitoring period (1996-2018). Positive area-change values reflect an increase in (and movement to) Urban/bare/lightly vegetated surfaces area during the respective time-steps, whereas negative area-change values reflect a decrease in (and movement from) Urban/bare/lightly vegetated surfaces area.

Area change to and from Scrub/shrubland

Between 1996 and 2018, Scrub/shrubland gained area predominantly from Grassland/other herbaceous vegetation, with a lesser contribution from Forest (Figure 7). The area lost from Scrub/shrubland over the same period was more evenly split between Grassland/other herbaceous vegetation and Forest. However, the relative apportionment between Grassland/other herbaceous vegetation and Forest in terms of area lost from Scrub/shrubland has shifted over time. During 1996-2001, area loss from Scrub/shrubland predominantly went to Forest, whereas most of the area lost after 2001 went to Grassland/other herbaceous vegetation.

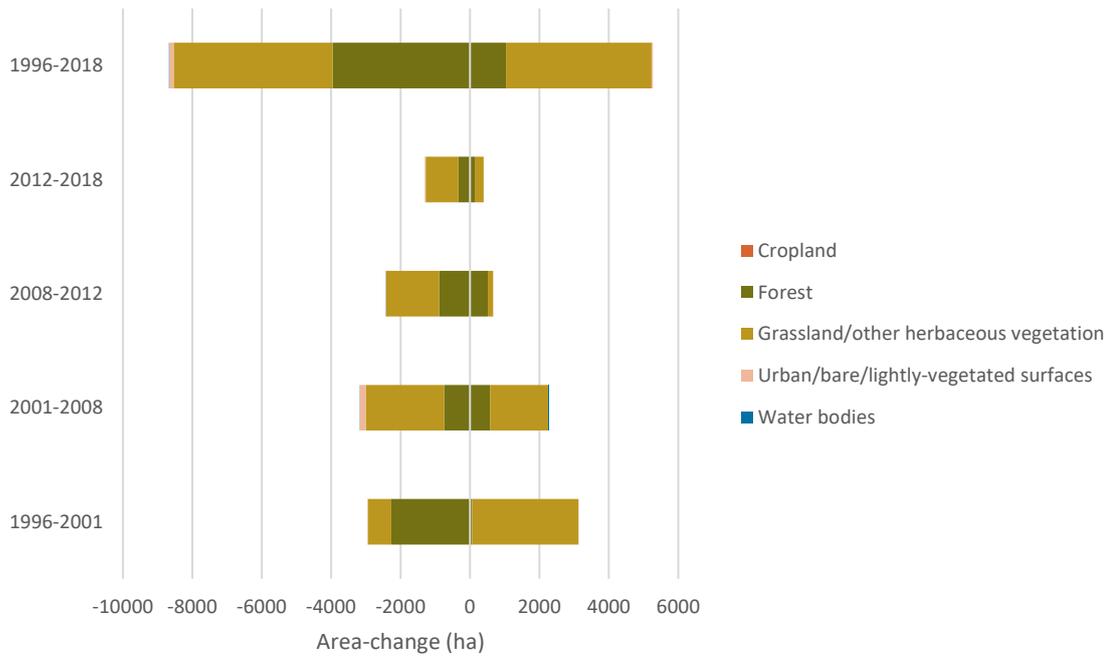


Figure 7. Changes in land area to and from the Scrub/shrubland class between individual time-steps (1996-2001, 2001-2008, 2008-2012, and 2012-2018) and across the entire monitoring period (1996-2018). Positive area-change values reflect an increase in (and movement to) Scrub/shrubland area during the respective time-steps, whereas negative area-change values reflect a decrease in (and movement from) Scrub/shrubland area.

Area change to and from Cropland

Cropland gained area predominantly from Grassland/other herbaceous vegetation, with a minor contribution from Forest cover (Figure 8) between 1996 and 2018. Almost all the gains in Cropland area occurred between 1996 and 2008. The area lost from Cropland across the entire monitoring period mostly went to Urban/bare/lightly-vegetated surfaces and Grassland/other herbaceous vegetation.

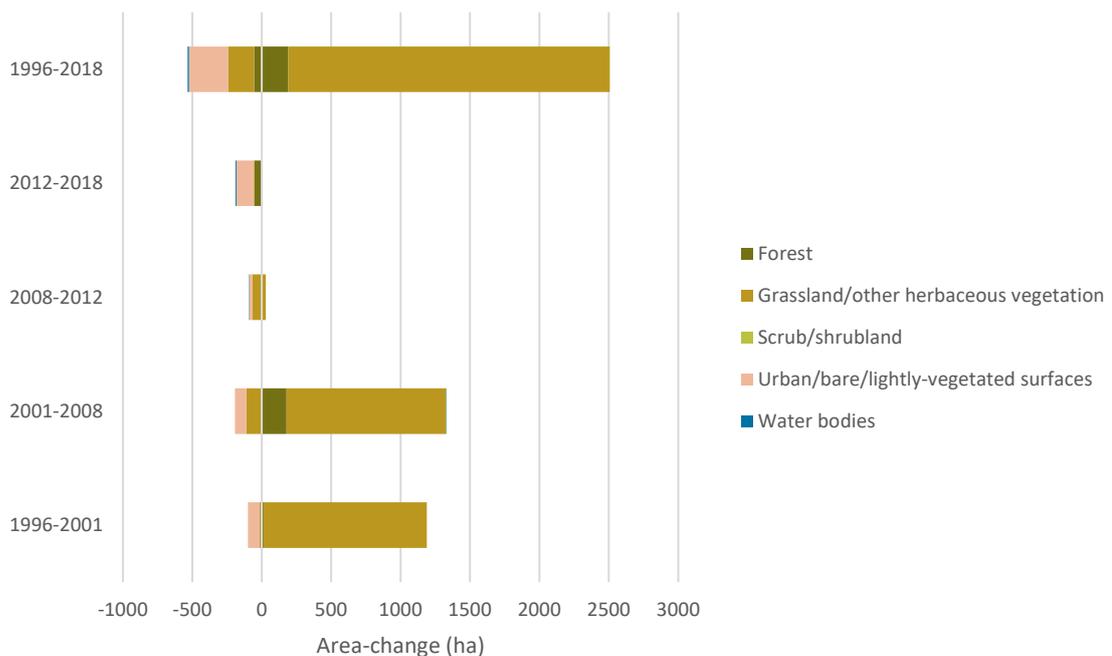


Figure 8. Changes in land area to and from the Cropland class between individual time-steps (1996-2001, 2001-2008, 2008-2012, and 2012-2018) and across the entire monitoring period (1996-2018). Positive area-change values reflect an increase in (and movement to)

Cropland area during the respective time-steps, whereas negative area-change values reflect a decrease in (and movement from) Cropland area.

3.2 Catchment management zone picture

3.2.1 Current state

The land cover profiles of the eight catchment management zones that subdivide the Waikato region, in 2018, vary considerably (Figure 9). Most zones have land cover profiles that are dominated by Grassland/other herbaceous vegetation, including Upper Waikato (55% of zone area) and Central Waikato (75% of zone area). The exceptions are Lake Taupo and Coromandel, where Grassland/other herbaceous vegetation occupies 18% and 19% of zone area respectively, and Forest is the predominant land cover (occupying 51% and 59% of zone area respectively). The Lake Taupo and Coromandel zones also have the largest proportions of Scrub/shrubland in the region, representing 9% and 20% of zone area respectively. A considerable area of Water bodies also characterises the Lake Taupo zone. The Central Waikato and Lower Waikato zones have the largest proportions of Cropland in the region, each with 3% of zone area. Urban/bare/lightly-vegetated surfaces occupy a notable proportion of zone area in the Central Waikato, where Hamilton City and some other urban centres (i.e. Cambridge) are situated. The distribution of the broad land cover classes within each of the catchment management zones as at the 2018 time-step is shown in Figure 2 (above).

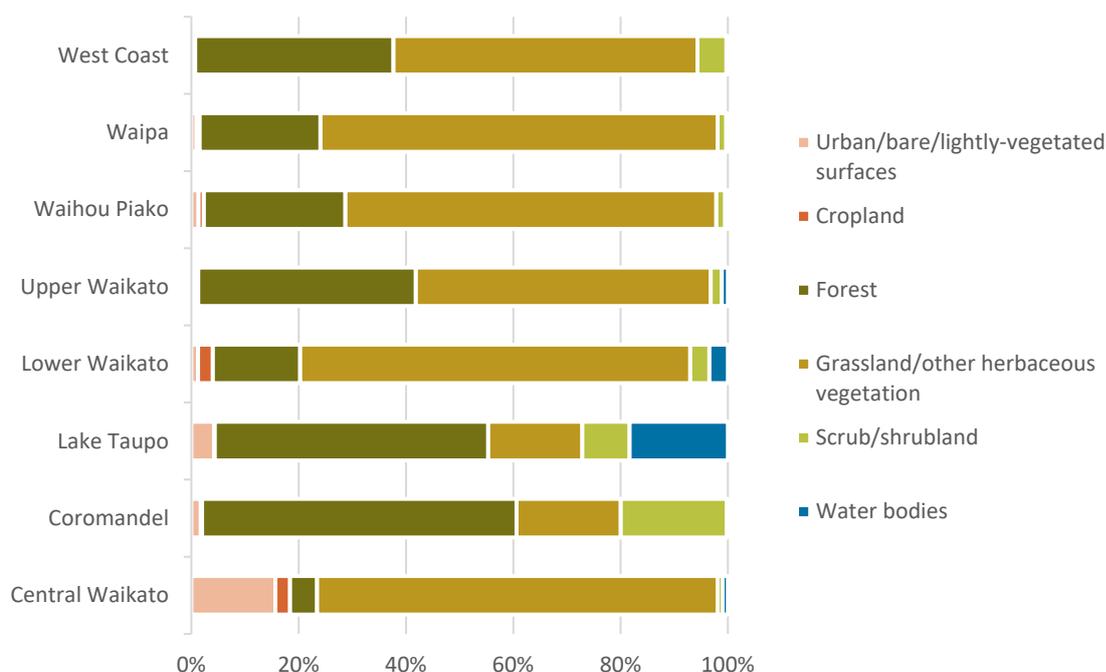


Figure 9. Proportion (%) of catchment management zone area occupied by broad land cover classes at the 2018 time-step (the current state).

More detail around the composition of the land cover profiles of the zones in 2018 described above is provided by a breakdown of the broad land cover classes by the medium-level classes (Table 5). In all zones, Grassland/other herbaceous vegetation is predominantly comprised of Exotic grassland. However, there is a substantial area (10,250 ha) of Other herbaceous vegetation (mostly herbaceous freshwater vegetation associated with the Kopuatai Peat Dome and other wetland areas) present in the Waihou Piako zone and a substantial area (7,923 ha) of Tussock grassland present in the Lake Taupo zone. The predominant constituent of Urban/bare/lightly-vegetated surfaces in most zones is Urban area. The exceptions to this are the Lake Taupo and West Coast zones where Natural/bare/lightly-vegetated surfaces predominate. Also, the Lower Waikato zone has a relatively substantial area (1,437 ha) of Artificial bare surfaces (largely Surface mines and dumps).

Table 5. Breakdown of broad land cover classes by medium-level classes showing the land area (ha) occupied by each medium level class at the 2018 time-step (the current state) for each catchment management zone.

Broad Classes	Medium Classes	2018 Area (ha)							
		Central Waikato	Coro-mandel	Lake Taupo	Lower Waikato	Upper Waikato	Waihou Piako	Waipa	West Coast
Urban/bare /lightly-vegetated surfaces	Artificial bare surfaces	257	111	451	1437	469	864	265	171
	Natural bare/lightly-vegetated surfaces	0	401	11276	124	57	12	111	1806
	Urban area	9708	2936	3179	2087	2598	4453	2623	743
Cropland	Cropping/horticulture	1745	477	323	7984	2425	3808	1732	306
Forest	Exotic forest	1060	29771	75685	22308	128708	27283	13348	24414
	Indigenous forest	2144	84698	102525	25138	46777	76787	55760	132449
Grassland/other herbaceous vegetation	Exotic grassland	47312	37005	50741	206977	236743	262453	226632	239102
	Other herbaceous vegetation	188	918	2600	4667	1093	10250	400	1564
	Tussock grassland	0	0	7923	0	45	0	0	0
Scrub/shrubland	Exotic scrub/shrubland	96	620	1639	1471	1942	714	1867	4049
	Indigenous scrub/shrubland	487	37963	29224	8908	7021	5782	3126	18805
Water bodies	Water bodies	629	416	64030	10070	4900	2058	876	1138

Indigenous forest is the predominant constituent of Forest cover in all zones except for Upper Waikato, where there Exotic forest is the primary constituent. However, the areas of Indigenous and Exotic forest in the Lower Waikato zone are similar (25,138 ha and 22,308 ha respectively). Scrub/shrubland is dominated by Indigenous scrub/shrubland in all zones.

3.2.2 Change over time

As for the regional picture, land cover change in catchment management zones during the 1996-2018 monitoring period mainly reflects shifts between Grassland/other herbaceous vegetation and Forest covers (Figure 10). However, in contrast to the regional picture, Forest area increased, and Grassland/other herbaceous vegetation area decreased over the monitoring period in all zones except the Upper Waikato. The Upper Waikato is notable, not only because the main land cover change is the opposite to that of all other zones, but also because the magnitude of the area change (about 45,000 ha) is at least five times greater than that observed

for the other zones (e.g. around 9,000 ha in the West Coast zone). This change reflects the significant (large-scale on an area basis) change from exotic forestry to dairy pasture use that is known to have occurred in the southern part of the Waikato region (i.e. in the Upper Waikato zone) beginning during the first decade of the twenty-first century (Cameron et al., 2009). An increase in the area of Urban/bare/lightly-vegetated surfaces in the Central Waikato zone and an increase in Cropland area in Lower Waikato between 1996 and 2018 is also evident. The Waihou Piako zone had the least land cover change over the period.

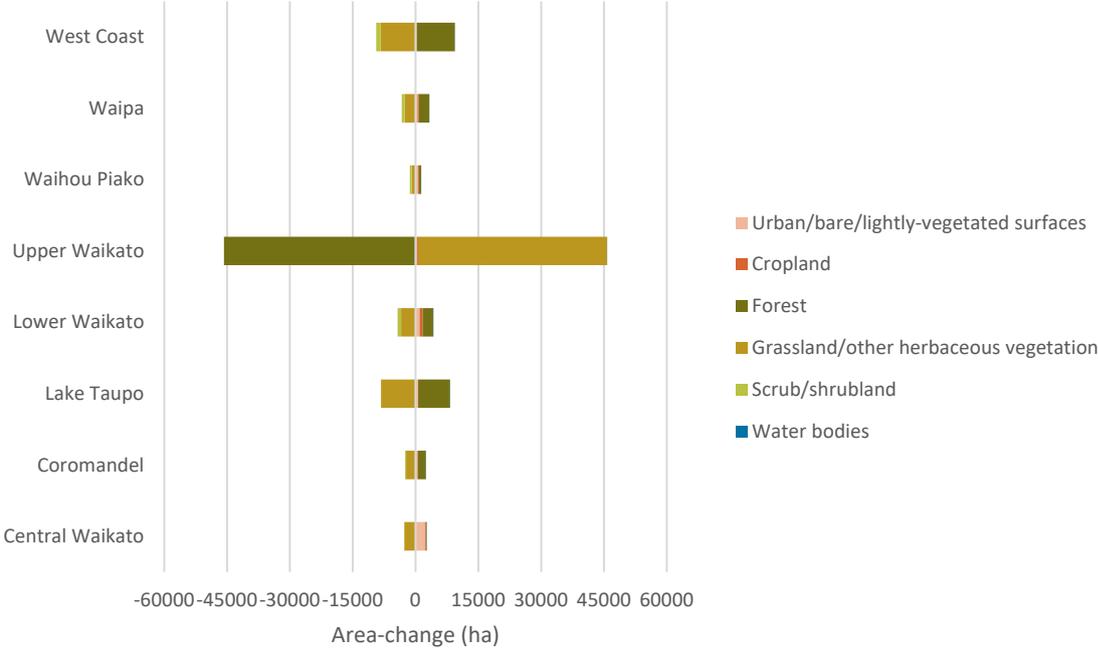


Figure 10. Net change in the land area occupied by broad land cover classes across the entire monitoring period (1996-2018) for each catchment management zone. Classes with positive area-change values had a net increase in area during the period, whereas classes with negative area-change values had a net decrease in area.

The changes in Grassland/other herbaceous vegetation within zones described above largely relate to changes in Exotic grassland and most of the changes in Forest cover relate to changes in Exotic forest (Table 6). For all zones, except Lower Waikato and West Coast, changes in Urban area accounted for most of the changes in the areas of Urban/bare/lightly-vegetated surfaces. Changes in the areas of Scrub/shrubland were split relatively evenly between Indigenous and Exotic scrub/shrubland in all zones except in Coromandel, where most of the area change related to Exotic scrub/shrubland.

Table 6. Breakdown of broad land cover classes by medium-level classes showing the net change in land area (ha) occupied by each medium level class across the entire monitoring period (1996-2018) for each catchment management zone.

Broad Classes	Medium Classes	1996-2018 Area-Change (ha)							
		Central Waikato	Coromandel	Lake Taupo	Lower Waikato	Upper Waikato	Waihou Piako	Waipua	West Coast
Urban/bare /lightly-vegetated surfaces	Artificial bare surfaces	92	23	-8	538	-2	178	43	82
	Natural bare/lightly-vegetated surfaces	0	0	10	0	1	0	0	68
	Urban area	2155	428	643	425	287	435	431	39
Cropland	Cropping/horticulture	218	125	-27	760	310	202	300	86
Forest	Exotic forest	209	2007	7688	2564	-46114	614	2434	9324
	Indigenous forest	12	-120	-107	-86	400	-102	59	-226
Grassland/other herbaceous vegetation	Exotic grassland	-2622	-2247	-8169	-3424	45058	-608	-2520	-8316
	Other herbaceous vegetation	-36	-2	-31	-11	8	-312	-71	-1
	Tussock grassland	0	0	0	0	45	0	0	0
Scrub/shrubland	Exotic scrub/shrubland	-29	-287	175	-485	192	-202	-492	-674
	Indigenous scrub/shrubland	-16	41	-194	-378	-199	-258	-200	-402
Water bodies	Water bodies	17	32	20	98	12	52	17	20

Area change to and from Forest

Area change to and from Forest for each catchment management zone during the period 1996-2018 is presented in Figure 11. In all zones, most of the change to and from Forest was from and to Grassland/other herbaceous vegetation. However, Forest also gained area over this period from Scrub/shrubland, particularly in the Coromandel and West Coast zones. Forest both gained area from, and lost area to, Scrub/shrubland in the Upper Waikato zone.

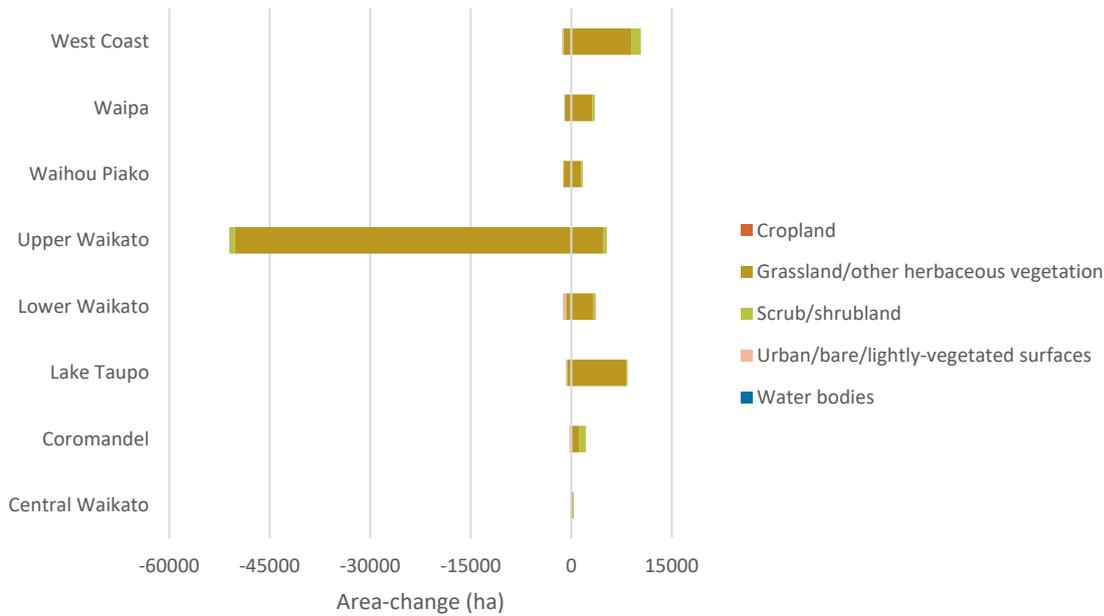


Figure 11. Changes in land area to and from the Forest class across the entire monitoring period (1996-2018) for each catchment management zone. Positive area-change values reflect an increase in (and movement to) Forest area during the period, whereas negative area-change values reflect a decrease in (and movement from) Forest area.

Area change to and from Grassland/other herbaceous vegetation

Much of the area change to and from Grassland/other herbaceous vegetation in most zones between 1996 and 2018 was from and to Forest (Figure 12). This was not the case for the Central Waikato and Coromandel zones. In Central Waikato, most of the area lost from Grassland/other herbaceous vegetation went to Urban/bare/lightly-vegetated surfaces, with a lesser area lost to Cropland. In the Coromandel zone, area was lost to both Forest and Scrub/shrubland in similar proportions. In the West Coast zone, Grassland/other herbaceous vegetation both gained and lost area in relatively substantial proportions to and from Scrub/shrubland.

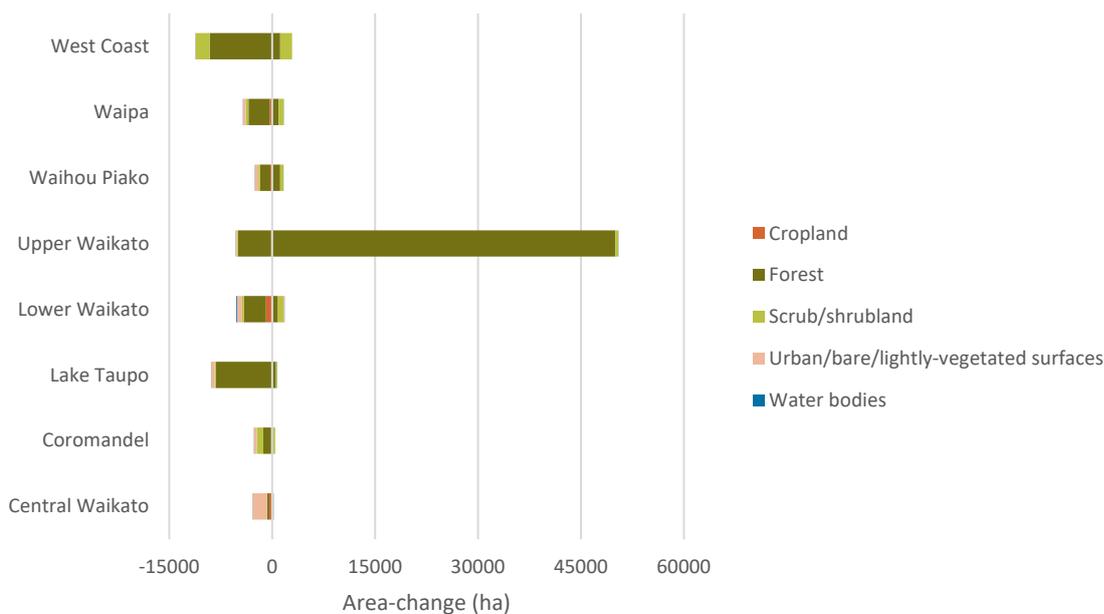


Figure 12. Changes in land area to and from the Grassland/other herbaceous vegetation class across the entire monitoring period (1996-2018) for each catchment management zone. Positive area-change values reflect an increase in (and movement to) Grassland/other herbaceous vegetation area during the period, whereas negative area-change values

reflect a decrease in (and movement from) Grassland/other herbaceous vegetation area.

Area change to and from Urban/bare/lightly vegetated surfaces

Urban/bare/lightly-vegetated surfaces predominantly gained area from Grassland/other herbaceous vegetation between 1996 and 2018 in most zones (Figure 13). In some zones (i.e. Lower Waikato, Upper Waikato, Lake Taupo, and Waihou Piako), Urban/bare/lightly-vegetated surfaces also gained area from Forest. In the West Coast zone, most of the area gain was from Forest. Urban/bare/lightly-vegetated surfaces lost area to both Grassland/other herbaceous vegetation and Forest in the Lower Waikato zone. Cropland contributed area to Urban/bare/lightly-vegetated surfaces over the period in the Central Waikato, Lower Waikato, and Waihou Piako zones.

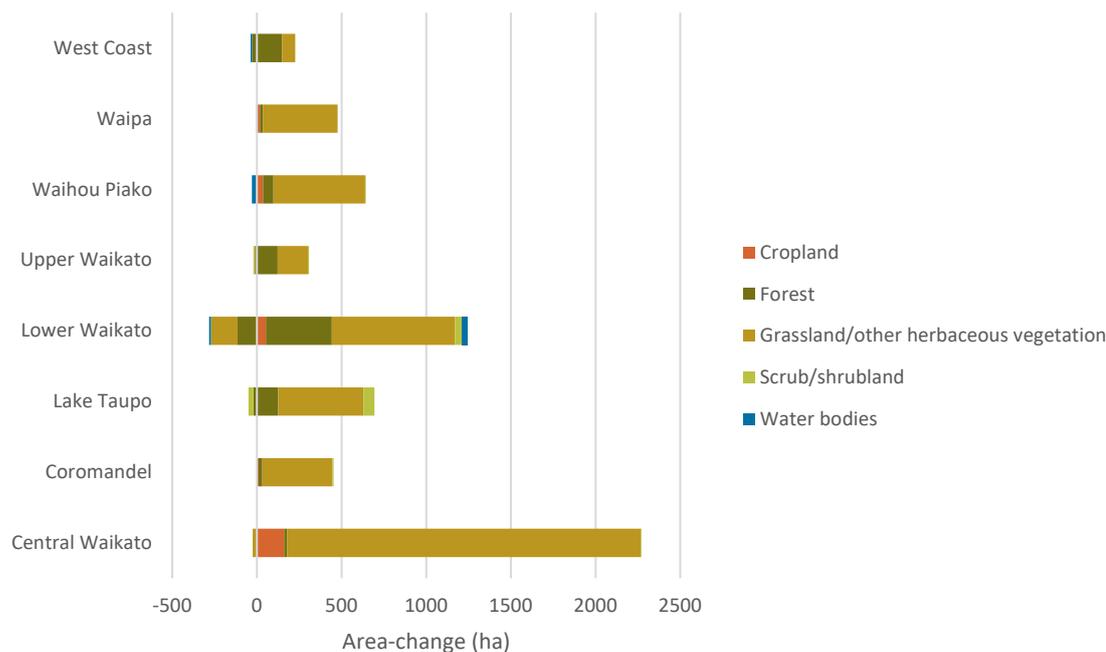


Figure 13. Changes in land area to and from the Urban/bare/lightly vegetated surfaces class across the entire monitoring period (1996-2018) for each catchment management zone. Positive area-change values reflect an increase in (and movement to) Urban/bare/lightly vegetated surfaces area during the period, whereas negative area-change values reflect a decrease in (and movement from) Urban/bare/lightly vegetated surfaces area.

Area change to and from Scrub/shrubland

In most zones, Scrub/shrubland predominantly gained area from Grassland/other herbaceous vegetation between 1996 and 2018 (Figure 14). The exception to this was the Upper Waikato, where most of the Scrub/shrubland area gain came from Forest. Scrub/shrubland area was lost to both Grassland/other herbaceous vegetation and Forest over the period. In the Lake Taupo zone, Scrub/shrubland also lost some area to Urban/bare/lightly vegetated surfaces.

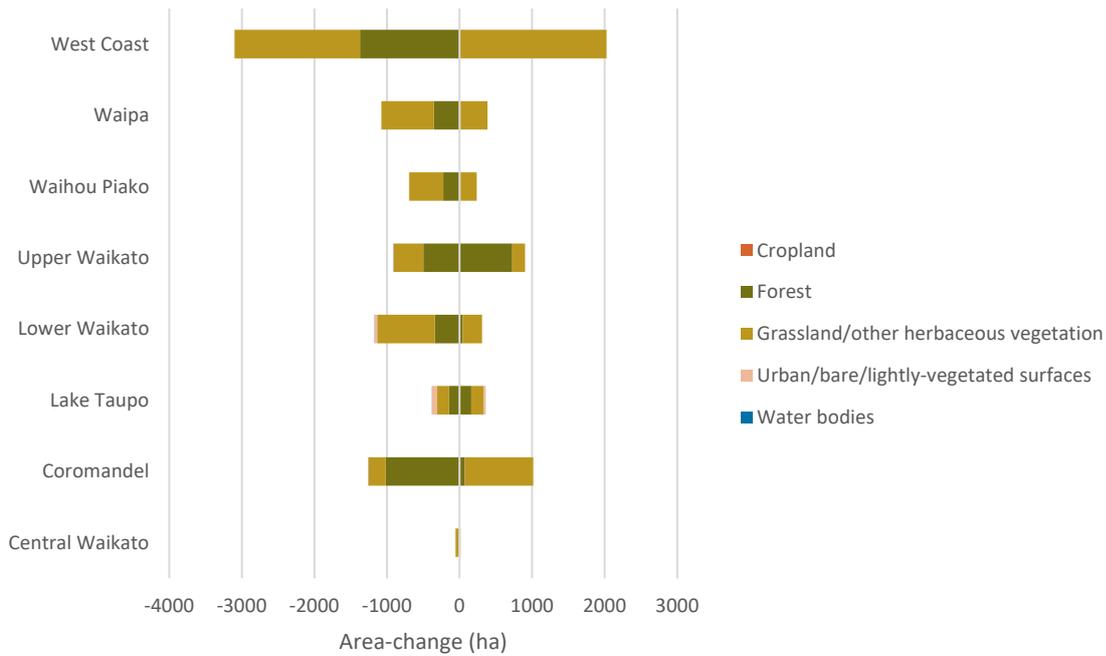


Figure 14. Changes in land area to and from the Scrub/shrubland class across the entire monitoring period (1996-2018) for each catchment management zone. Positive area-change values reflect an increase in (and movement to) Scrub/shrubland area during the period, whereas negative area-change values reflect a decrease in (and movement from) Scrub/shrubland area.

Area change to and from Cropland

In most zones, Cropland predominantly gained area from Grassland/other herbaceous vegetation during the period 1996-2018 (Figure 15). The exception to this was the Upper Waikato where Cropland gained area from both Forest (the predominant source) and Grassland/other herbaceous vegetation. Cropland predominantly lost area to: Grassland/other herbaceous vegetation in the Lower Waikato; Urban/bare/lightly vegetated surfaces in Central Waikato, Waihou Piako, Waipa, and Coromandel; and Forest in the Lake Taupo zone.

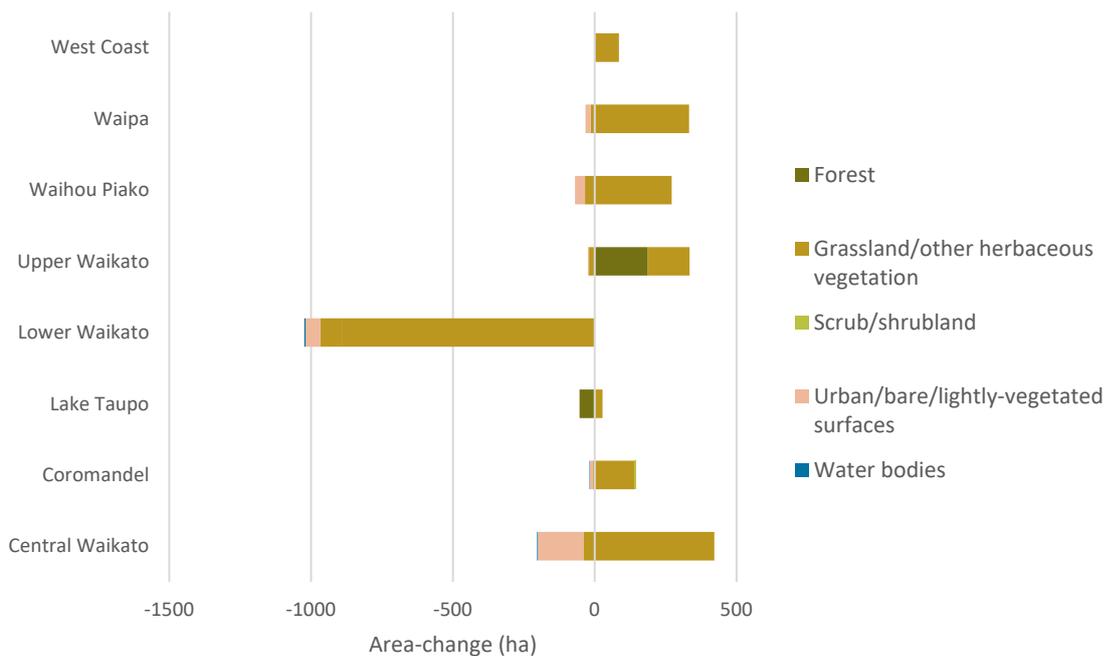


Figure 15. Changes in land area to and from the Cropland class across the entire monitoring period (1996-2018) for each catchment management zone. Positive area-change values reflect

an increase in (and movement to) Cropland area during the period, whereas negative area-change values reflect a decrease in (and movement from) Cropland area.

3.3 Land cover as a proxy for land use

Land cover data can provide a general indication of regional land use and land use change over time.

3.3.1 Regional picture

Current state

The current state of land use in the Waikato region, reflected in the proportion of regional area (2,466,629 ha) occupied by the land use classes as at the 2018 time-step, is presented in Figure 16. Land use in the Waikato region is dominated by pastoral use with pastoral grazing occupying 53% of regional area. Exotic forestry is also a significant land use in the region, occupying 12% of regional area. Urban area and Cropping/horticulture represent relatively small proportions of regional area, at around 1% each, and Transport/other infrastructure accounts for less than 1%. The remainder of the regional area is occupied by Indigenous land cover (28%), Other exotic vegetation (1%), and Water bodies (4%). Although Indigenous land cover (comprising all indigenous forest, scrub/shrubland, and herbaceous vegetation covers) and Other exotic vegetation (comprising exotic scrub/shrubland and deciduous hardwood vegetation) could largely be considered ‘unused’ land use classes in relation to primary production, settlements, or industry, these areas will encompass a range of other ‘uses’ such as biodiversity conservation, erosion control, carbon sequestration, and recreation.

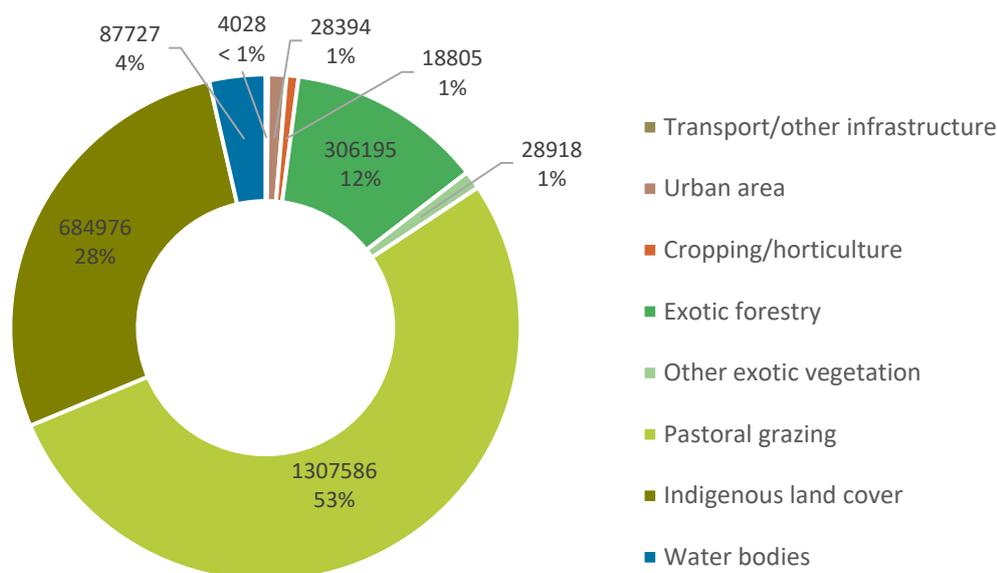


Figure 16. Proportion (%) of regional area occupied by land use classes at the 2018 time-step (the current state). Area (ha) values for each class are presented. Regional land area is 2,466,629 ha.

The distribution of the land use classes across the Waikato region in 2018 is shown in Figure 17. Exotic forestry tends to be situated in the south-eastern parts of the region and Indigenous land cover where the terrain is generally steeper (e.g. in the north-eastern and western parts of the region).

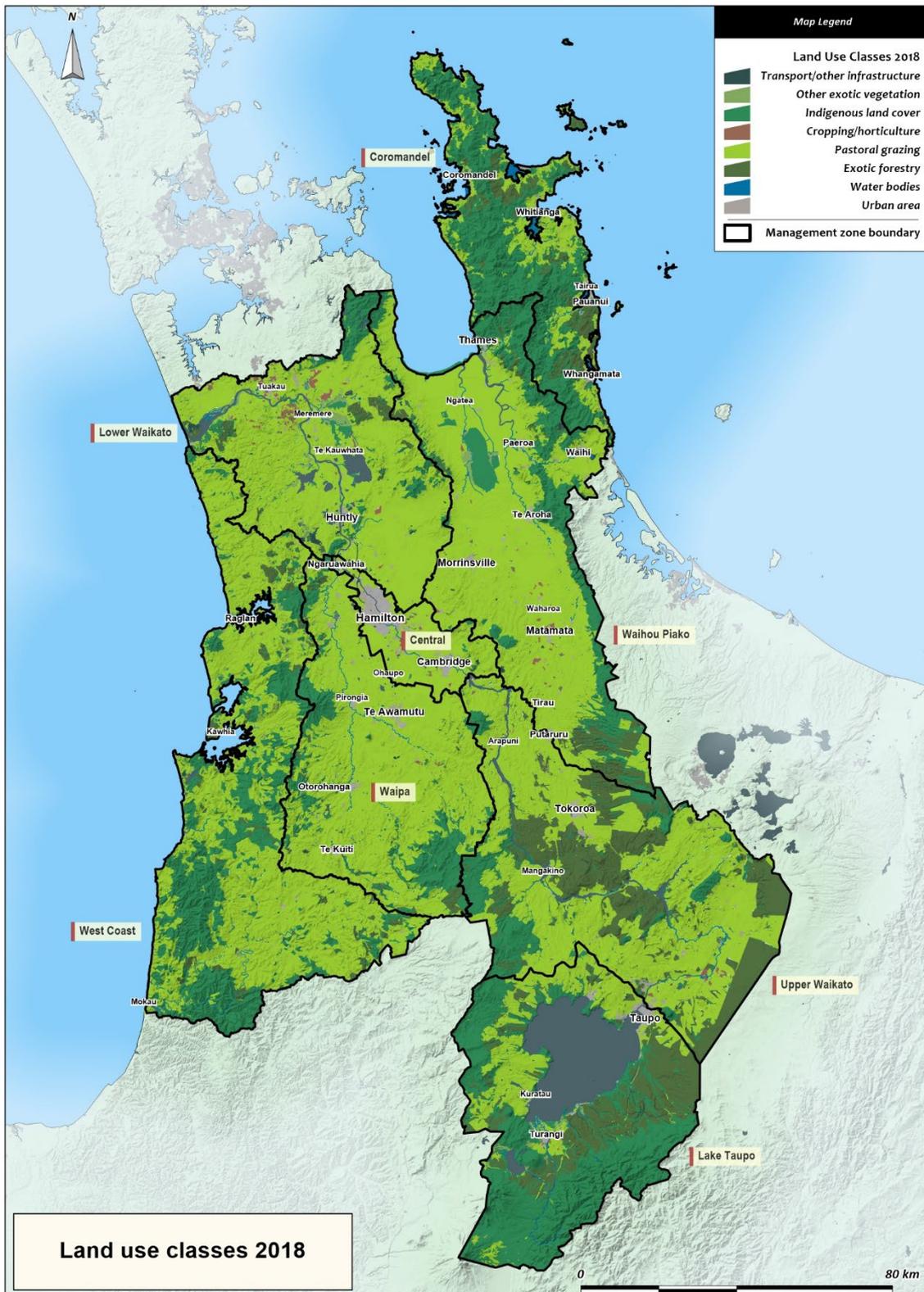


Figure 17. Map showing the distribution of the land use classes across the Waikato region as at the 2018 time-step.

Change over time

Pastoral grazing and Exotic forestry are the land use classes that have exhibited the largest changes in net area over the monitoring period (Figure 18). However, the direction of net change observed between 1996 and 2001, during which time the area of Exotic forestry increased by 22,338 ha and the area of Pastoral grazing decreased by about 25,000 ha, was reversed in subsequent time-steps. After 2001, the area of Pastoral grazing in the region increased by between about 18,000 ha and 9,000 ha (net) in each time-step, whereas the area of exotic forest decreased by between around 17,000 ha and 9,000 ha (net). There were also net decreases in the areas of Indigenous land cover and Other exotic vegetation after 2001.

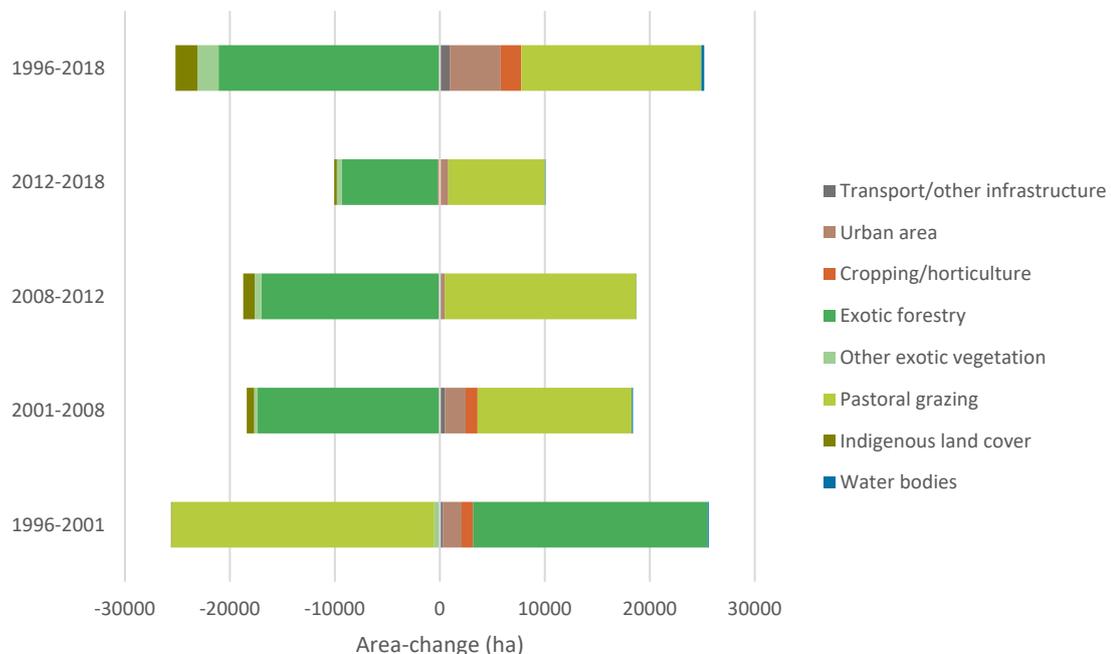


Figure 18. Net change in the land area occupied by land use classes between individual time-steps (1996-2001, 2001-2008, 2008-2012, and 2012-2018) and across the entire monitoring period (1996-2018). Classes with positive area-change values had a net increase in area during the respective time-steps, whereas classes with negative area-change values had a net decrease in area.

There were net increases in Urban area in all time-steps, but the increases were greatest during 2001-2008 and 1996-2001 (about 2,000 ha and 1,700 ha respectively). Also, during 2001-2008 and 1996-2001, net increases in Cropping/horticulture area were at their greatest (about 1,100 ha in each time-step).

Over the entire monitoring period (1996-2018), land use change in the Waikato region was characterised by: net increases in the areas of Pastoral grazing, Urban area, Cropping/horticulture, and Transport/other infrastructure; and net decreases in the areas of Exotic forestry, Indigenous land cover, and Other exotic vegetation. Together, these changes reflect an intensification of land use, particularly in terms of the shift from forestry to pastoral uses.

3.3.2 Catchment management zone picture

Current state

In 2018, the land use profiles of the eight catchment management zones that subdivide the Waikato region vary considerably (Figure 19). Land use in most zones is dominated by Pastoral grazing, except for Lake Taupo and Coromandel where Indigenous land cover is predominant (representing 44% and 63% of zone area respectively). Indigenous land cover also accounts for a substantial proportion of zone area in the West Coast (36%). The Waipa and Central Waikato zones have the largest proportions (74% for both) of zone area occupied by Pastoral grazing. Exotic forestry occurs in most zones, but accounts for substantial proportions of zone area in the Upper Waikato, Lake Taupo, and Coromandel zones. Cropping/horticulture accounted for notable proportions of zone area in Lower Waikato and Central Waikato (3% for both). Urban area represents a substantial proportion (15%) of zone area in the Central Waikato as this zone encompasses the urban areas of Hamilton city and the town of Cambridge. The distribution of the land use classes within each of the catchment management zones as at the 2018 time-step is shown in Figure 17 (above).

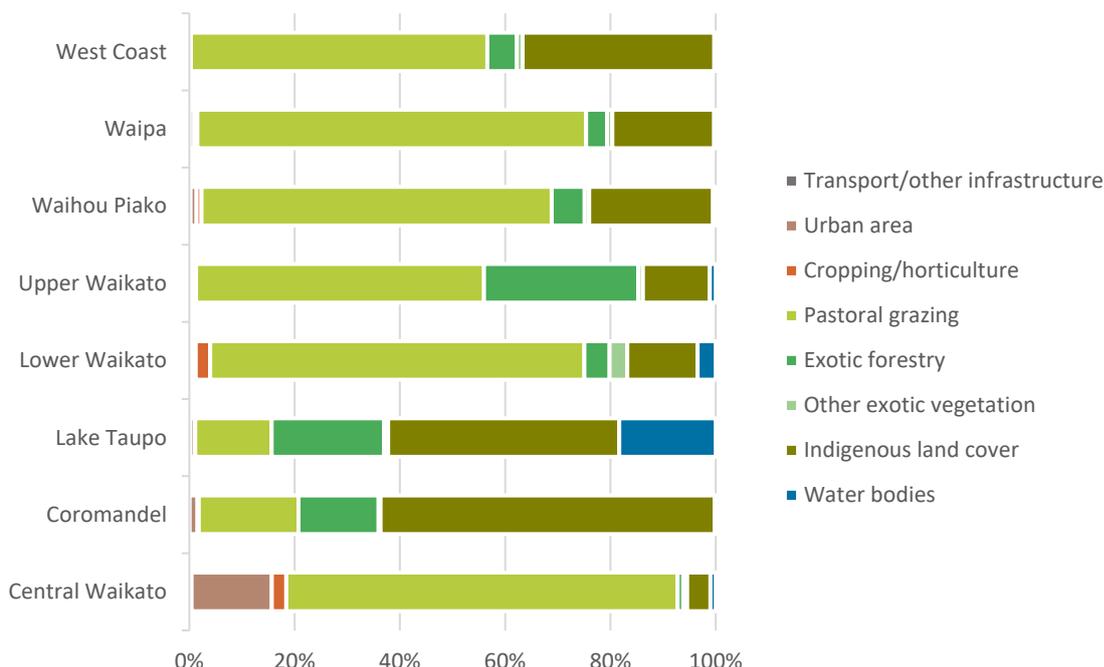


Figure 19. Proportion (%) of catchment management zone area occupied by land use classes at the 2018 time-step (the current state).

Change over time

Over the entire monitoring period (1996-2018), net change in land use has predominantly been between Exotic forestry and Pastoral grazing in most zones (Figure 20). The exception to this is the Central Waikato zone, where the main land use change over the monitoring period has been between Pastoral grazing and Urban area. In this case, the net area of Pastoral grazing decreased, and net Urban area increased, indicating that urban expansion has occurred in this zone. Of the zones where the main change was between Exotic forestry and Pastoral grazing, all but one zone experienced afforestation (i.e. the net area of Exotic forest increased, and the net area of Pastoral grazing decreased) over the monitoring period. In the Upper Waikato zone, where the net area of land use change was at least five times greater than in the other zones, substantial deforestation occurred (i.e. the net area of Exotic forest decreased by almost 46,000 ha and the net area of Pastoral grazing increased by about 45,000 ha) over the monitoring period, representing a substantial intensification of land use in that zone and for the region as a whole. This change, which began in the first decade of the twenty-first century (Cameron et al., 2009) and appears to have been ongoing since 2001 (see Figure 18), has commonly been referred to as the 'pine to pasture conversion' (e.g. . There was a notable increase in the net area of Cropping/horticulture over the monitoring period in the Lower Waikato zone.

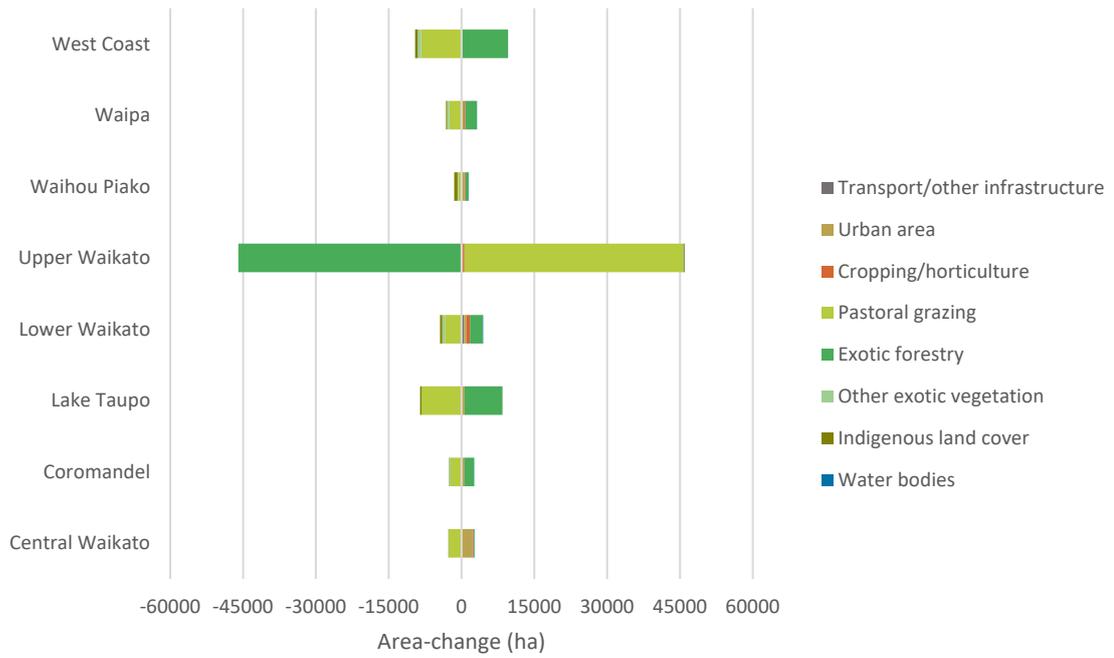


Figure 20. Net change in the land area occupied by land use classes across the entire monitoring period (1996-2018) for each catchment management zone. Classes with positive area-change values had a net increase in area during the period, whereas classes with negative area-change values had a net decrease in area.

4 Summary

4.1 Land cover

4.1.1 Regional picture

The land cover of the Waikato region is currently (as at 2018) dominated by Exotic grassland cover (at 53% of regional area). There is also a substantial area of Forest cover (comprising both Indigenous and Exotic forest covers, although Indigenous forest predominates). Also of note is that Scrub/shrubland occupies about 5% of regional area.

Over the monitoring period (1996-2018), net deforestation (i.e. a net decrease in Exotic forest area) and a net decrease in the area of Scrub/shrubland has occurred. In contrast, net increases in the areas under Exotic grassland, Urban area, and Cropland occurred over the same period. The deforestation occurred between 2001 and 2018, with the reverse trend (i.e. net afforestation) apparent between 1996 and 2001. Much of the net increases in the areas of Cropland and Urban area occurred between 1996 and 2008, although the increase in Urban area continued after 2008 at a lesser rate. Most of the area lost from Exotic forest became Exotic grassland. This change has often been referred to as 'pine to pasture conversion' (e.g. . Most of the gains in the areas of Cropland and Urban area came from Exotic grassland cover.

4.1.2 Catchment management zone picture

There is considerable variation in land cover profiles across the region. Most catchment management zones have profiles dominated by Exotic grassland cover. However, the Lake Taupo and Coromandel zones have profiles dominated more by Forest (particularly Indigenous forest) and Scrub/Shrubland covers. Cropland cover is relatively more prominent in the Central and Lower Waikato zones. Central Waikato's land cover profile also includes a relatively high proportion of Urban area as this zone encompasses the urban areas of Hamilton city and the town of Cambridge.

In contrast to the regional picture, net afforestation occurred in most catchment management zones over the monitoring period (1996-2018). However, these changes are overwhelmingly overshadowed by the large net deforestation that occurred in the Upper Waikato zone over the same period. This net deforestation reflects the large-scale 'pine to pasture conversion' that has occurred in the Upper Waikato since 2001. Consistent with the regional picture, the gains and losses in areas of the land cover classes were dominated by shifts between Exotic Forest and Exotic grassland.

4.2 Land cover as a proxy for land use

The land cover data was reclassified and used as a proxy to provide a general indication of regional land use and land use change over time.

4.2.1 Regional picture

Current (as at 2018) regional land use is dominated by pastoral grazing (other work, e.g. Fenton et al., 2001, has suggested that slightly more than 50% of the area of pastoral grazing in the region is used for dairying, with the remainder used for drystock grazing). Exotic forestry is also a significant land use type in the region (occupying about 12% of regional area). However, this area is substantially smaller than the area occupied by Indigenous cover (representing 28% of regional area). Cropping/horticulture is a relatively minor land use in the region on an area basis.

Net increases in Pastoral grazing, Cropping/horticulture, and Urban area over the monitoring period (1996-2018) were observed. Net decreases in Exotic forestry and Indigenous cover (predominantly Indigenous forest) were also observed, the latter occurring mainly between

2001 and 2012. These changes are indicative of an overall trend of land use intensification in the region over this period.

4.2.2 Catchment management zone picture

As for land cover, there are substantial variations in the land use profiles across the region. In most zones the dominant land use type is Pastoral grazing. However, the Lake Taupo and Coromandel zones have substantial proportions of Indigenous cover as well as some exotic forestry (and relatively little pastoral grazing). The Upper Waikato zone has the largest proportion of Exotic forestry whereas the Central Waikato has the largest proportion of Urban area. The Central and Lower Waikato zones have the largest proportions of Cropping/horticulture in the region.

Over the monitoring period (1996-2018) a net increase in Exotic forestry area was observed for most zones. However, these changes were overshadowed by the large-scale 'pine to pasture conversion' that had occurred in the Upper Waikato zone, resulting in a substantial net increase in pastoral grazing area in that zone (and for the region as a whole).

5 Conclusions and recommendations

Based on the analysis of land cover (and land use) state and trend as presented and described above, we conclude that:

- The Waikato region currently has a land cover profile that is dominated by Exotic grassland and that this is indicative of a land use profile dominated by pastoral grazing.
- The major land cover/use change that has occurred in the region over the monitoring period (1996-2018) has been the net deforestation resulting from the large-scale 'pine to pasture conversion' that has occurred since 2001, primarily in the Upper Waikato zone.
- Land cover/use profiles vary by catchment management zone across the region, with those of the Lake Taupo and Coromandel zones being substantially different to those of the other zones (having higher proportions of Forest cover). Also, the Upper Waikato zone differed substantially from the other zones in terms of the magnitude and direction of land cover/use change (i.e. the large-scale 'pine to pasture conversion').
- The expansion of Cropping/horticulture mainly occurred between 1996 and 2008 and has subsequently slowed.
- Urban area has expanded throughout the monitoring period, but the magnitude of increases was variable following the substantial increases observed between 1996 and 2008.
- The land cover/use changes observed, particularly the net increases in the areas of Pastoral grazing, Urban area, and Cropping/horticulture, are indicative of an overall trend of land use intensification in the region over the monitoring period (but particularly since 2001).
- Although land cover data can provide a useful high-level proxy for land use, it cannot differentiate between types of pastoral grazing use (i.e. between dairying and drystock grazing).

Recommendations for further work include:

- Indicators and maps of land cover, land use, land use intensification, and land fragmentation currently in use regionally (and nationally) make use of variable input data, time-steps, and classifications which makes alignment and interoperability difficult. This has highlighted a need for a common development framework for land resource information to support improved interoperability and interpretation of aligned indicators and map layers.
- The Waikato Regional Council (and region) would benefit from the development of a region-wide land use monitoring and mapping programme purpose-designed to support policy development, State of the Environment reporting, and various modelling platforms (e.g. the Waikato Regional Prioritisation Framework, etc.).

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Appendices

Appendix 1: Description of the classes of LCDB v5.0

Table A1-1. Description of the LCDB v5.0 classes (Source: Manaaki Whenua – Landcare Research, [LCDB Classes At Version5 - LCDB](#) | [Environment and Land GIS](#) | [LRIS Portal](#) (scinfo.org.nz))

Detailed Classes	Class Description
Transport infrastructure	Artificial surfaces associated with transport such as arterial roads, rail-yards and airport runways. Skid sites and landings associated with forest logging are sometimes also included.
Surface mine or dump	Bare surfaces arising from open-cast and other surface mining activities, quarries, gravel-pits and areas of solid waste disposal such as refuse dumps, clean-fill dumps and active reclamation sites.
Sand or gravel	Bare surfaces dominated by unconsolidated materials generally finer than coarse gravel (60mm). Typically mapped along sandy seashores and the margins of lagoons and estuaries, lakes and rivers and some areas subject to surficial erosion, soil toxicity and extreme exposure.
Landslide	Bare surfaces arising from mass-movement erosion generally in mountainlands and steep hill-country.
Gravel or rock	Bare surfaces dominated by unconsolidated or consolidated materials generally coarser than coarse gravel (60mm). Typically mapped along rocky seashores and rivers, sub-alpine and alpine areas, scree slopes and erosion pavements.
Permanent snow and ice	Areas where ice and snow persists through late summer. Typically occurring above 1800m but also at lower elevations as glaciers.
Alpine grass/herbfield	Typically sparse communities above the actual or theoretical treeline dominated by herbaceous cushion, mat, turf, and rosette plants and lichens. Grasses are a minor or infrequent component, whereas stones, boulders and bare rock are usually conspicuous.
Built-up area (settlement)	Commercial, industrial or residential buildings, including associated infrastructure and amenities, not resolvable as other classes. Low density 'lifestyle' residential areas are included where hard surfaces, landscaping and gardens dominate other land covers.
Urban parkland/open space	Open, mainly grassed or sparsely-treed, amenity, utility and recreation areas. The class includes parks and playing fields, public gardens, cemeteries, golf courses, berms and other vegetated areas usually within or associated with built-up areas.
Short-rotation cropland	Land regularly cultivated for the production of cereal, root, and seed crops, hops, vegetables, strawberries and field nurseries, often including intervening grassland, fallow land, and other covers not delineated separately.
Orchards, vineyards or other perennial crops	Land managed for the production of grapes, pip, citrus and stone fruit, nuts, olives, berries, kiwifruit, and other perennial crops. Cultivation for crop renewal is infrequent and irregular but is sometimes practiced for weed control.
Forest - harvested	Predominantly bare ground arising from the harvesting of exotic forest or, less commonly, the clearing of indigenous forest. Replanting of exotic forest (or conversion to a new land use) is not evident and nor is the future use of land cleared of indigenous forest.
Exotic forest	Planted or naturalised forest predominantly of radiata pine but including other pine species, Douglas fir, cypress, larch, acacia and eucalypts. Production forestry is the main land use in this class with minor areas devoted to mass-movement erosion-control and other areas of naturalised (wildling) establishment.
Deciduous hardwoods	Exotic deciduous woodlands, predominantly of willows or poplars but also of oak, elm, ash or other species. Commonly alongside inland water (or as part of wetlands), or as erosion-control, shelter and amenity plantings.
Indigenous forest	Tall forest dominated by indigenous conifer, broadleaved or beech species.
Broadleaved indigenous hardwoods	Lowland scrub communities dominated by indigenous mixed broadleaved shrubs such as wineberry, mahoe, five-finger, Pittosporum spp, fuchsia, tutu, titoki and tree ferns. This class is usually indicative of advanced succession toward indigenous forest.
Depleted grassland	Areas, of mainly former short tussock grassland in the drier eastern South Island high country, degraded by over-grazing, fire, rabbits and weed invasion among which Hieracium species are conspicuous. Short tussocks usually occur, as do exotic grasses, but bare ground is more prominent.
High producing exotic grassland	Exotic sward grassland of good pastoral quality and vigour reflecting relatively high soil fertility and intensive grazing management. Clover species, ryegrass and cocksfoot dominate with lucerne and plantain locally important, but also including lower-producing grasses exhibiting vigour in areas of good soil moisture and fertility.
Low producing grassland	Exotic sward grassland and indigenous short tussock grassland of poor pastoral quality reflecting lower soil fertility and extensive grazing management or non-agricultural use. Browntop, sweet vernal, danthonia, fescue and Yorkshire fog dominate, with indigenous short tussocks (hard tussock, blue tussock and silver tussock) common in the eastern South Island and locally elsewhere.
Herbaceous freshwater vegetation	Herbaceous wetland communities occurring in freshwater habitats where the water table is above or just below the substrate surface for most of the year. The class includes rush, sedge, restiad, and sphagnum communities and other wetland species, but not flax nor willows which are mapped as Flaxland and Deciduous Hardwoods respectively.
Flaxland	Areas dominated by New Zealand flax usually swamp flax (harakeke) in damp sites but occasionally mountain flax (wharariki) on cliffs and mountain slopes.

Herbaceous saline vegetation	Herbaceous wetland communities occurring in saline habitats subject to tidal inundation or saltwater intrusion. Commonly includes club rush, wire rush and glasswort, but not mangrove which is mapped separately.
Tall tussock grassland	Indigenous snow tussocks in mainly alpine mountain-lands and red tussock in the central North Island and locally in poorly-drained valley floors, terraces and basins of both islands.
Gorse and/or Broom	Scrub communities dominated by gorse or Scotch broom generally occurring on sites of low fertility, often with a history of fire, and insufficient grazing pressure to control spread. Left undisturbed, this class can be transitional to Broadleaved Indigenous Hardwoods.
Mixed exotic shrubland	Communities of introduced shrubs and climbers such as boxthorn, hawthorn, elderberry, blackberry, sweet brier, buddleja, and old man's beard.
Manuka and/or Kanuka	Scrub dominated by mānuka and/or kānuka, typically as a successional community in a reversion toward forest. Mānuka has a wider ecological tolerance and distribution than kānuka with the latter somewhat concentrated in the north with particular prominence on the volcanic soils of the central volcanic plateau.
Matagouri or Grey scrub	Scrub and shrubland comprising small-leaved, often divaricating shrubs such as matagouri, Coprosma spp, Muehlenbeckia spp., Casinnia spp., and Parsonsia spp. These, from a distance, often have a grey appearance.
Fernland	Bracken fern, umbrella fern, or ring fern, commonly on sites with low fertility and a history of burning. Manuka, gorse, and/or other shrubs are often a component of these communities and will succeed Fernland if left undisturbed.
Sub-alpine shrubland	Highland scrub dominated by indigenous low-growing shrubs including species of Hebe, Dracophyllum, Olearia, and Cassinia. Predominantly occurring above the actual or theoretical treeline, this class is also recorded where temperature inversions have created cooler microclimates at lower elevations (e.g. the 'frost flats' of the central North Island).
Mangrove	Shrubs or small trees of the New Zealand mangrove (<i>Avicennia marina</i> subspecies <i>australascia</i>) growing in harbours, estuaries, tidal creeks and rivers north of Kawhia on the west coast and Ohiwa on the east coast.
Lake or pond	Essentially permanent, open, fresh-water without emerging vegetation including artificial features such as oxidation ponds, amenity, farm and fire ponds and reservoirs as well as natural lakes, ponds and tarns.
River	Flowing open fresh-water generally more than 30m wide and without emerging vegetation. It includes artificial features such as canals and channels as well as natural rivers and streams.
Estuarine open water	Standing or flowing saline water without emerging vegetation including estuaries, lagoons, and occasionally lakes occurring in saline situations such as inter-dune hollows and coastal depressions.
Not land	Used where the shoreline has moved between time-steps and no other appropriate class is available to represent an area outside the coastline.

Appendix 2: Regional land cover/use area and area-change data

Table A2-1. Broad land cover class area and area-change (ha) data for each time-step.

Broad Classes	Area 1996 (ha)	Area 2001 (ha)	Area 2008 (ha)	Area 2012 (ha)	Area 2018 (ha)	Area-change 2001-1996 (ha)	Area-change 2008-2001 (ha)	Area-change 2012-2008 (ha)	Area-change 2018-2012 (ha)	Area-change 2018-1996 (ha)
Regional area	2466629	2466629	2466629	2466629	2466629	0	0	0	0	0
Urban/bare/lightly-vegetated surfaces	40866	42947	45377	45842	46736	2081	2430	465	894	5870
Cropland	16831	17921	19055	18991	18805	1090	1134	-64	-186	1974
Forest	870659	892558	875226	858326	849218	21899	-17333	-16900	-9108	-21441
Grassland/other herbaceous vegetation	1321133	1295779	1310355	1328604	1337861	-25354	14575	18250	9256	16728
Scrub/shrubland	129689	129860	128958	127193	126283	171	-902	-1765	-910	-3406
Water bodies	87451	87563	87659	87672	87727	112	96	13	55	276

Table A2-2. Medium land cover class area and area-change (ha) data for each time-step.

Medium Classes	Area 1996 (ha)	Area 2001 (ha)	Area 2008 (ha)	Area 2012 (ha)	Area 2018 (ha)	Area-change 1996-2001 (ha)	Area-change 2001-2008 (ha)	Area-change 2008-2012 (ha)	Area-change 2012-2018 (ha)	Area-change 1996-2018 (ha)
Regional area	2466629	2466629	2466629	2466629	2466629	0	0	0	0	0
Artificial bare surfaces	3081	3391	3885	4034	4028	311	493	150	-7	947
Natural bare/lightly-vegetated surfaces	14237	14243	14212	14217	14315	6	-31	5	98	78
Urban area	23549	25313	27280	27591	28394	1764	1968	310	803	4845
Cropping/horticulture	16831	17921	19055	18991	18805	1090	1134	-64	-186	1974
Exotic forest	343938	366268	348886	331845	322667	22329	-17382	-17041	-9177	-21271
Indigenous forest	526720	526291	526340	526482	526551	-430	49	141	69	-170
Exotic grassland	1290441	1265418	1280116	1298377	1307586	-25023	14697	18261	9209	17145
Other herbaceous vegetation	22775	22445	22322	22311	22313	-331	-122	-11	2	-462
Tussock grassland	7916	7916	7916	7916	7962	0	0	0	45	45
Exotic scrub/shrubland	14252	13734	13429	12886	12446	-519	-305	-543	-440	-1806
Indigenous scrub/shrubland	115436	116126	115529	114307	113836	690	-597	-1222	-470	-1600
Water bodies	87451	87563	87659	87672	87727	112	96	13	55	276

Table A2-3. Detailed land cover class area and area-change (ha) data for each time-step.

Detailed Classes	Area 1996 (ha)	Area 2001 (ha)	Area 2008 (ha)	Area 2012 (ha)	Area 2018 (ha)	Area-change 1996-2001 (ha)	Area-change 2001-2008 (ha)	Area-change 2008-2012 (ha)	Area-change 2012-2018 (ha)	Area-change 1996-2018 (ha)
Regional area	2466629	2466629	2466629	2466629	2466629	0	0	0	0	0
Transport Infrastructure	874	882	910	1022	1012	8	27	112	-10	138
Surface Mine or Dump	2207	2509	2975	3012	3016	302	466	37	3	809
Sand or Gravel	2671	2667	2635	2637	2734	-3	-32	2	98	64
Landslide	27	31	31	31	31	4	0	0	0	4
Gravel or Rock	9013	9018	9019	9022	9022	5	1	4	0	10
Permanent Snow and Ice	205	205	205	205	205	0	0	0	0	0
Alpine Grass/Herbfield	2322	2322	2322	2322	2322	0	0	0	0	0
Built-up Area (settlement)	19164	20898	22779	23082	23868	1733	1882	303	785	4703
Urban Parkland/Open Space	4384	4415	4501	4509	4526	31	86	8	18	142
Short-rotation Cropland	14740	15741	16540	16527	16361	1001	799	-13	-166	1621
Orchard, Vineyard, Other Perennial Crop	2091	2180	2515	2464	2444	89	335	-51	-20	353
Forest - Harvested	31690	35290	31026	14299	27041	3600	-4263	-16727	12742	-4648
Exotic Forest	295584	314322	301234	301025	279154	18738	-13087	-210	-21871	-16430
Deciduous Hardwoods	16665	16657	16625	16520	16472	-9	-32	-104	-49	-193
Indigenous Forest	455774	455485	455389	455335	455246	-289	-96	-54	-89	-528
Broadleaved Indigenous Hardwoods	70946	70805	70951	71147	71304	-141	146	195	158	358
Depleted Grassland	1137	1137	1137	1137	1137	0	0	0	0	0
High Producing Exotic Grassland	1274165	1252334	1265399	1282737	1290548	-21831	13064	17338	7811	16383
Low Producing Grassland	15140	11947	13580	14503	15901	-3192	1633	923	1398	761
Herbaceous Freshwater Vegetation	20579	20249	20088	20071	20073	-331	-160	-17	2	-506
Flaxland	309	309	359	359	359	0	50	0	0	50
Herbaceous Saline Vegetation	1887	1887	1875	1881	1881	0	-12	6	0	-6
Tall Tussock Grassland	7916	7916	7916	7916	7962	0	0	0	45	45

Gorse and/or Broom	12604	12071	11720	11149	10752	-533	-352	-571	-397	-1852
Mixed Exotic Shrubland	1648	1663	1709	1737	1694	14	47	28	-43	46
Manuka and/or Kanuka	102239	102933	102333	101103	100632	694	-600	-1230	-471	-1607
Matagouri or Grey Scrub	59	61	59	59	59	2	-2	0	0	0
Fernland	285	278	289	297	298	-7	11	8	1	13
Sub Alpine Shrubland	10164	10164	10164	10164	10164	0	0	0	0	0
Mangrove	2690	2690	2684	2684	2684	0	-6	0	0	-6
Lake or Pond	75031	75144	75209	75230	75279	112	66	21	49	248
River	7233	7233	7232	7225	7225	0	-1	-7	0	-8
Estuarine Open Water	5186	5186	5217	5217	5217	0	31	0	0	31

Table A2-4. Area-change data (ha) to and from broad land cover classes.

Change	Broad Classes	Area-change 1996-2001 (ha)	Area-change 2001-2008 (ha)	Area-change 2008-2012 (ha)	Area-change 2012-2018 (ha)	Area-change 1996-2018 (ha)
To Forest	Cropland	2	0	0	53	55
	Grassland/other herbaceous vegetation	20367	4852	5810	3429	31361
	Scrub/shrubland	2268	743	892	331	3951
	Urban/bare/lightly-vegetated surfaces	12	63	156	0	183
	Water bodies	0	5	0	0	5
From Forest	Cropland	-13	-179	0	0	-191
	Grassland/other herbaceous vegetation	-423	-22000	-23037	-12583	-54840
	Scrub/shrubland	-57	-576	-515	-136	-1038
	Urban/bare/lightly-vegetated surfaces	-249	-238	-200	-200	-899
	Water bodies	-7	-3	-6	-3	-28
To Grassland/other herbaceous vegetation	Cropland	15	112	69	4	187
	Forest	423	22000	23037	12583	54840
	Scrub/shrubland	674	2257	1524	943	4584
	Urban/bare/lightly-vegetated surfaces	39	50	62	173	185
	Water bodies	0	10	8	9	27
From Grassland/other herbaceous vegetation	Cropland	-1176	-1146	-30	-4	-2313
	Forest	-20367	-4852	-5810	-3429	-31361
	Scrub/shrubland	-3068	-1691	-152	-257	-4193
	Urban/bare/lightly-vegetated surfaces	-1796	-2097	-436	-731	-4977
	Water bodies	-96	-66	-24	-35	-252
To Urban/bare/lightly-vegetated surfaces	Cropland	83	81	22	125	282
	Forest	249	238	200	200	899
	Grassland/other herbaceous vegetation	1796	2097	436	731	4977
	Scrub/shrubland	16	173	15	29	126

	Water bodies	0	8	42	24	36
From Urban/bare/lightly-vegetated surfaces	Cropland	0	0	0	0	0
	Forest	-12	-63	-156	0	-183
	Grassland/other herbaceous vegetation	-39	-50	-62	-173	-185
	Scrub/shrubland	-3	-4	-2	0	-36
	Water bodies	-9	-51	-29	-43	-47
To Scrub/shrubland	Cropland	0	0	0	0	0
	Forest	57	576	515	136	1038
	Grassland/other herbaceous vegetation	3068	1691	152	257	4193
	Urban/bare/lightly-vegetated surfaces	3	4	2	0	36
	Water bodies	0	9	0	0	0
From Scrub/shrubland	Cropland	0	-4	0	0	-4
	Forest	-2268	-743	-892	-331	-3951
	Grassland/other herbaceous vegetation	-674	-2257	-1524	-943	-4584
	Urban/bare/lightly-vegetated surfaces	-16	-173	-15	-29	-126
	Water bodies	0	-6	-2	0	-8
To Cropland	Forest	13	179	0	0	191
	Grassland/other herbaceous vegetation	1176	1146	30	4	2313
	Scrub/shrubland	0	4	0	0	4
	Urban/bare/lightly-vegetated surfaces	0	0	0	0	0
	Water bodies	0	0	0	0	0
From Cropland	Forest	-2	0	0	-53	-55
	Grassland/other herbaceous vegetation	-15	-112	-69	-4	-187
	Scrub/shrubland	0	0	0	0	0
	Urban/bare/lightly-vegetated surfaces	-83	-81	-22	-125	-282
	Water bodies	0	2	-3	-8	-9

Table A2-5. Land use class area and area-change (ha) data for each time-step.

Land Use Classes	Area 1996 (ha)	Area 2001 (ha)	Area 2008 (ha)	Area 2012 (ha)	Area 2018 (ha)	Area-change 1996-2001 (ha)	Area-change 2001-2008 (ha)	Area-change 2008-2012 (ha)	Area-change 2012-2018 (ha)	Area-change 1996-2018 (ha)
Regional area	2466629	2466629	2466629	2466629	2466629	0	0	0	0	0
Transport/other infrastructure	3081	3391	3885	4034	4028	311	493	150	-7	947
Urban area	23549	25313	27280	27591	28394	1764	1968	310	803	4845
Cropping/horticulture	16831	17921	19055	18991	18805	1090	1134	-64	-186	1974
Exotic forestry	327273	349611	332261	315324	306195	22338	-17350	-16937	-9129	-21078
Other exotic vegetation	30918	30390	30054	29406	28918	-527	-337	-647	-488	-1999
Pastoral grazing	1290441	1265418	1280116	1298377	1307586	-25023	14697	18261	9209	17145
Indigenous land cover	687086	687021	686320	685233	684976	-65	-701	-1087	-256	-2109
Water bodies	87451	87563	87659	87672	87727	112	96	13	55	276

Appendix 3: Catchment management zone land cover/use area and area-change data

Table A3-1. Broad land cover class area and area-change (ha) data for each time-step.

Zone	Broad Classes	Area 1996 (ha)	Area 2001 (ha)	Area 2008 (ha)	Area 2012 (ha)	Area 2018 (ha)	Area-change 1996-2001 (ha)	Area-change 2001-2008 (ha)	Area-change 2008-2012 (ha)	Area-change 2012-2018 (ha)	Area-change 1996-2018 (ha)
Central Waikato	Zone Area	63625	63625	63625	63625	63625	0	0	0	0	0
	Urban/bare/lightly-vegetated surfaces	7718	8644	9312	9433	9965	925	668	121	532	2247
	Cropland	1526	1596	1864	1851	1745	69	269	-13	-106	218
	Forest	2983	3259	3268	3243	3204	276	9	-25	-39	221
	Grassland/other herbaceous vegetation	50158	48885	47965	47893	47500	-1273	-920	-72	-393	-2658
	Scrub/shrubland	628	627	600	584	583	0	-27	-16	-2	-45
	Water bodies	612	615	616	621	629	3	1	5	8	17
Coromandel	Zone Area	195318	195318	195318	195318	195318	0	0	0	0	0
	Urban/bare/lightly-vegetated surfaces	2997	3192	3427	3434	3448	195	235	6	15	451
	Cropland	353	357	482	477	477	4	125	-5	0	125
	Forest	112582	113989	114498	114588	114469	1407	508	90	-118	1887
	Grassland/other herbaceous vegetation	40173	39035	37875	37819	37924	-1137	-1161	-56	105	-2249
	Scrub/shrubland	38829	38347	38620	38585	38583	-482	273	-35	-2	-246
	Water bodies	384	397	416	416	416	13	19	0	0	32
Lake Taupo	Zone Area	349596	349596	349596	349596	349596	0	0	0	0	0
	Urban/bare/lightly-vegetated surfaces	14261	14439	14853	14873	14906	177	414	21	33	645
	Cropland	350	364	376	376	323	15	12	0	-53	-27
	Forest	170629	171984	171621	175169	178210	1355	-363	3548	3041	7581
	Grassland/other herbaceous vegetation	69464	67786	67729	64233	61264	-1678	-57	-3496	-2969	-8200
	Scrub/shrubland	30882	30981	30989	30916	30863	99	8	-73	-53	-19
	Water bodies	64010	64042	64028	64029	64030	32	-14	1	2	20

	Zone Area	291171	291171	291171	291171	291171	0	0	0	0	0
	Urban/bare/lightly-vegetated surfaces	2686	3011	3430	3547	3648	326	419	117	101	963
	Cropland	7224	7616	8018	8006	7984	391	402	-11	-22	760
Lower Waikato	Forest	44968	47527	47843	47844	47446	2559	316	1	-398	2478
	Grassland/other herbaceous vegetation	215078	211817	211197	211239	211643	-3261	-619	41	404	-3435
	Scrub/shrubland	11243	11198	10643	10490	10379	-45	-555	-153	-111	-864
	Water bodies	9972	10003	10040	10045	10070	31	38	5	25	98
	Zone Area	432778	432778	432778	432778	432778	0	0	0	0	0
	Urban/bare/lightly-vegetated surfaces	2837	2870	2960	3083	3124	33	90	123	41	287
	Cropland	2115	2241	2426	2425	2425	126	184	0	0	310
Upper Waikato	Forest	221198	226971	206769	185828	175485	5773	-20202	-20941	-10343	-45714
	Grassland/other herbaceous vegetation	192770	187191	206769	227449	237882	-5579	19577	20680	10433	45111
	Scrub/shrubland	8970	8618	8965	9099	8963	-353	347	134	-136	-7
	Water bodies	4888	4888	4890	4896	4900	0	3	5	4	12
	Zone Area	394464	394464	394464	394464	394464	0	0	0	0	0
	Urban/bare/lightly-vegetated surfaces	4716	4929	5264	5294	5329	213	335	29	36	613
	Cropland	3606	3756	3845	3812	3808	149	89	-33	-4	202
Waihou Piako	Forest	103558	104864	104725	104509	104070	1305	-138	-217	-438	512
	Grassland/other herbaceous vegetation	273622	271975	271758	272204	272702	-1646	-218	447	498	-920
	Scrub/shrubland	6956	6909	6809	6590	6496	-47	-100	-219	-95	-460
	Water bodies	2006	2031	2063	2055	2058	25	31	-7	3	52
	Zone Area	306739	306739	306739	306739	306739	0	0	0	0	0
	Urban/bare/lightly-vegetated surfaces	2525	2726	2942	2958	2999	201	217	15	41	474
	Cropland	1432	1701	1747	1733	1732	269	46	-14	0	300
Waipa	Forest	66615	69146	69609	69607	69108	2531	463	-1	-499	2493
	Grassland/other herbaceous vegetation	229622	226551	226139	226491	227031	-3072	-412	352	540	-2591
	Scrub/shrubland	5685	5749	5427	5074	4992	64	-322	-354	-81	-693

	Water bodies	860	867	875	876	876	7	8	1	0	17
	Zone Area	424548	424548	424548	424548	424548	0	0	0	0	0
	Urban/bare/lightly-vegetated surfaces	2531	2541	2592	2624	2721	10	51	32	97	190
	Cropland	220	286	293	306	306	66	6	13	0	86
West Coast	Forest	147765	154451	156520	157169	156863	6686	2070	649	-307	9097
	Grassland/other herbaceous vegetation	248984	241291	239684	240036	240667	-7694	-1606	352	630	-8317
	Scrub/shrubland	23929	24860	24334	23285	22854	931	-526	-1049	-431	-1075
	Water bodies	1119	1119	1124	1128	1138	1	5	3	11	20

Table A3-2. Medium land cover class area and area-change (ha) data for each time-step.

Zone	Medium Classes	Area 1996 (ha)	Area 2001 (ha)	Area 2008 (ha)	Area 2012 (ha)	Area 2018 (ha)	Area-change 1996-2001 (ha)	Area-change 2001-2008 (ha)	Area-change 2008-2012 (ha)	Area-change 2012-2018 (ha)	Area-change 1996-2018 (ha)
Central Waikato	Zone Area	63625	63625	63625	63625	63625	0	0	0	0	0
	Artificial bare surfaces	165	181	211	263	257	16	30	52	-6	92
	Urban area	7553	8463	9100	9170	9708	910	638	70	538	2155
	Cropping/horticulture	1526	1596	1864	1851	1745	69	269	-13	-106	218
	Exotic forest	851	1117	1116	1099	1060	267	-1	-17	-39	209
	Indigenous forest	2132	2142	2152	2144	2144	10	10	-8	0	12
	Exotic grassland	49934	48697	47777	47705	47312	-1237	-920	-72	-393	-2622
	Other herbaceous vegetation	224	188	188	188	188	-36	0	0	0	-36
	Exotic scrub/shrubland	125	128	103	96	96	3	-25	-7	0	-29
	Indigenous scrub/shrubland	503	500	497	488	487	-3	-2	-9	-2	-16
	Water bodies	612	615	616	621	629	3	1	5	8	17
Coromandel	Zone Area	195318	195318	195318	195318	195318	0	0	0	0	0
	Artificial bare surfaces	88	88	106	109	111	0	18	3	2	23
	Natural bare/lightly-vegetated surfaces	401	401	401	401	401	0	0	0	0	0
	Urban area	2508	2703	2920	2924	2936	195	217	3	13	428
	Cropping/horticulture	353	357	482	477	477	4	125	-5	0	125
	Exotic forest	27764	29310	29807	29877	29771	1546	497	70	-106	2007
	Indigenous forest	84818	84680	84691	84710	84698	-138	11	19	-12	-120
	Exotic grassland	39252	38115	36955	36900	37005	-1137	-1161	-55	105	-2247
	Other herbaceous vegetation	921	920	920	918	918	-1	0	-2	0	-2
	Exotic scrub/shrubland	907	512	653	619	620	-395	141	-34	1	-287
	Indigenous scrub/shrubland	37921	37835	37967	37966	37963	-87	132	-1	-3	41
Water bodies	384	397	416	416	416	13	19	0	0	32	
Lake Taupo	Zone Area	349596	349596	349596	349596	349596	0	0	0	0	0

	Artificial bare surfaces	459	434	448	451	451	-25	14	3	0	-8
	Natural bare/lightly-vegetated surfaces	11266	11266	11267	11276	11276	0	1	9	0	10
	Urban area	2536	2739	3138	3146	3179	202	399	9	33	643
	Cropping/horticulture	350	364	376	376	323	15	12	0	-53	-27
	Exotic forest	67997	69339	69079	72632	75685	1342	-260	3553	3053	7688
	Indigenous forest	102632	102645	102542	102537	102525	13	-103	-5	-12	-107
	Exotic grassland	58910	57256	57207	53710	50741	-1655	-49	-3496	-2969	-8169
	Other herbaceous vegetation	2630	2607	2600	2600	2600	-23	-8	0	0	-31
	Tussock grassland	7923	7923	7923	7923	7923	0	0	0	0	0
	Exotic scrub/shrubland	1464	1497	1589	1633	1639	32	92	44	6	175
	Indigenous scrub/shrubland	29418	29484	29400	29283	29224	66	-84	-117	-59	-194
	Water bodies	64010	64042	64028	64029	64030	32	-14	1	2	20
	Zone Area	291171	291171	291171	291171	291171	0	0	0	0	0
Lower Waikato	Artificial bare surfaces	900	1144	1438	1439	1437	244	293	2	-2	538
	Natural bare/lightly-vegetated surfaces	124	130	130	124	124	5	0	-5	0	0
	Urban area	1662	1738	1863	1984	2087	76	125	121	103	425
	Cropping/horticulture	7224	7616	8018	8006	7984	391	402	-11	-22	760
	Exotic forest	19744	22340	22713	22736	22308	2596	373	23	-428	2564
	Indigenous forest	25224	25187	25130	25108	25138	-37	-57	-23	30	-86
	Exotic grassland	210400	207147	206551	206587	206977	-3254	-596	37	389	-3424
	Other herbaceous vegetation	4678	4670	4647	4652	4667	-8	-23	5	15	-11
	Exotic scrub/shrubland	1957	1878	1559	1501	1471	-78	-319	-58	-30	-485
	Indigenous scrub/shrubland	9286	9320	9084	8989	8908	34	-236	-95	-81	-378
	Water bodies	9972	10003	10040	10045	10070	31	38	5	25	98
	Zone Area	432778	432778	432778	432778	432778	0	0	0	0	0
Upper Waikato	Artificial bare surfaces	471	470	464	478	469	-1	-5	13	-8	-2
	Natural bare/lightly-vegetated surfaces	55	52	49	57	57	-3	-3	7	0	1

	Urban area	2311	2348	2446	2548	2598	37	98	102	50	287
	Cropping/horticulture	2115	2241	2426	2425	2425	126	184	0	0	310
	Exotic forest	174822	180745	160311	139163	128708	5924	-20434	-21148	-10456	-46114
	Indigenous forest	46377	46226	46458	46664	46777	-151	232	206	113	400
	Exotic grassland	191684	186105	205701	226355	236743	-5579	19595	20654	10387	45058
	Other herbaceous vegetation	1086	1086	1068	1093	1093	0	-18	25	0	8
	Tussock grassland	0	0	0	0	45	0	0	0	45	45
	Exotic scrub/shrubland	1750	1440	1843	2100	1942	-310	403	256	-158	192
	Indigenous scrub/shrubland	7221	7177	7121	6999	7021	-43	-56	-123	22	-199
	Water bodies	4888	4888	4890	4896	4900	0	3	5	4	12
	Zone Area	394464	394464	394464	394464	394464	0	0	0	0	0
	Artificial bare surfaces	686	756	831	854	864	70	75	23	10	178
	Natural bare/lightly-vegetated surfaces	12	12	12	12	12	0	0	0	0	0
	Urban area	4018	4161	4422	4428	4453	144	260	6	25	435
	Cropping/horticulture	3606	3756	3845	3812	3808	149	89	-33	-4	202
	Exotic forest	26669	28030	27889	27708	27283	1361	-141	-181	-425	614
	Indigenous forest	76889	76833	76836	76800	76787	-56	3	-36	-13	-102
	Exotic grassland	263061	261678	261470	261940	262453	-1383	-208	470	513	-608
	Other herbaceous vegetation	10561	10298	10288	10264	10250	-263	-10	-24	-14	-312
	Exotic scrub/shrubland	916	906	902	773	714	-10	-3	-130	-59	-202
	Indigenous scrub/shrubland	6040	6003	5907	5817	5782	-37	-96	-89	-35	-258
	Water bodies	2006	2031	2063	2055	2058	25	31	-7	3	52
	Zone Area	306739	306739	306739	306739	306739	0	0	0	0	0
	Artificial bare surfaces	222	226	250	265	265	4	24	15	0	43
	Natural bare/lightly-vegetated surfaces	111	111	111	111	111	0	0	0	0	0
	Urban area	2192	2389	2582	2582	2623	197	193	0	41	431
	Cropping/horticulture	1432	1701	1747	1733	1732	269	46	-14	0	300

	Exotic forest	10914	13437	13894	13847	13348	2523	457	-48	-499	2434
	Indigenous forest	55701	55709	55714	55761	55760	8	6	46	-1	59
	Exotic grassland	229151	226080	225717	226092	226632	-3072	-363	375	540	-2520
	Other herbaceous vegetation	471	471	422	399	400	0	-49	-23	0	-71
	Exotic scrub/shrubland	2359	2394	2130	1890	1867	35	-264	-240	-24	-492
	Indigenous scrub/shrubland	3326	3355	3297	3183	3126	29	-58	-114	-58	-200
	Water bodies	860	867	875	876	876	7	8	1	0	17
	Zone Area	424548	424548	424548	424548	424548	0	0	0	0	0
	Artificial bare surfaces	88	91	135	173	171	3	44	38	-2	82
	Natural bare/lightly-vegetated surfaces	1738	1742	1713	1707	1806	4	-29	-6	99	68
	Urban area	704	707	744	744	743	3	36	0	0	39
	Cropping/horticulture	220	286	293	306	306	66	6	13	0	86
West Coast	Exotic forest	15090	21851	23975	24684	24414	6761	2125	709	-271	9324
	Indigenous forest	132675	132600	132545	132485	132449	-75	-55	-60	-36	-226
	Exotic grassland	247419	239725	238128	238473	239102	-7694	-1597	346	629	-8316
	Other herbaceous vegetation	1565	1566	1557	1563	1564	0	-9	6	1	-1
	Exotic scrub/shrubland	4722	4932	4600	4225	4049	210	-332	-375	-177	-674
	Indigenous scrub/shrubland	19207	19927	19734	19060	18805	721	-193	-674	-255	-402
	Water bodies	1119	1119	1124	1128	1138	1	5	3	11	20

Table A3-3. Area-change data (ha) to and from broad land cover classes across the entire monitoring period (1996-2018) by catchment management zone.

Change	Broad Classes	Area-change 1996-2018 (ha)							
		Central Waikato	Coromandel	Lake Taupo	Lower Waikato	Upper Waikato	Waihou Piako	Waipa	West Coast
To Forest	Cropland	0	0	53	0	0	0	2	0
	Grassland/other herbaceous vegetation	313	1164	8196	3230	4823	1498	3116	9015
	Scrub/shrubland	6	1013	144	342	498	223	353	1372
	Urban/bare/lightly-vegetated surfaces	0	0	20	115	12	6	1	29
	Water bodies	0	0	0	5	0	0	1	0
From Forest	Cropland	0	-1	0	0	-187	0	-2	0
	Grassland/other herbaceous vegetation	-82	-193	-545	-762	-50005	-1138	-945	-1160
	Scrub/shrubland	0	-74	-162	-45	-728	-14	-14	-8
	Urban/bare/lightly-vegetated surfaces	-17	-21	-126	-389	-118	-63	-17	-149
	Water bodies	0	0	0	-17	-9	0	-1	-2
To Grassland/other herbaceous vegetation	Cropland	40	6	0	75	20	34	13	0
	Forest	82	193	545	762	50005	1138	945	1160
	Scrub/shrubland	50	236	171	793	410	470	725	1729
	Urban/bare/lightly-vegetated surfaces	24	0	0	158	3	0	0	0
	Water bodies	1	0	7	11	1	7	0	0
From Grassland/other herbaceous vegetation	Cropland	-422	-138	-27	-892	-147	-272	-330	-86
	Forest	-313	-1164	-8196	-3230	-4823	-1498	-3116	-9015
	Scrub/shrubland	-14	-941	-170	-266	-174	-223	-371	-2019
	Urban/bare/lightly-vegetated surfaces	-2091	-413	-504	-728	-179	-541	-441	-77
	Water bodies	-15	-28	-27	-117	-5	-35	-16	-10
To Urban/bare/lightly-vegetated surfaces	Cropland	161	11	1	53	4	35	18	0
	Forest	17	21	126	389	118	63	17	149
	Grassland/other herbaceous vegetation	2091	413	504	728	179	541	441	77
	Scrub/shrubland	3	8	65	38	7	4	0	1

	Water bodies	0	0	0	36	0	0	0	0
From Urban/bare/lightly-vegetated surfaces	Cropland	0	0	0	0	0	0	0	0
	Forest	0	0	-20	-115	-12	-6	-1	-29
	Grassland/other herbaceous vegetation	-24	0	0	-158	-3	0	0	0
	Scrub/shrubland	0	0	-30	0	-7	0	0	0
	Water bodies	0	-2	0	-10	0	-24	-1	-8
To Scrub/shrubland	Cropland	0	0	0	0	0	0	0	0
	Forest	0	74	162	45	728	14	14	8
	Grassland/other herbaceous vegetation	14	941	170	266	174	223	371	2019
	Urban/bare/lightly-vegetated surfaces	0	0	30	0	7	0	0	0
	Water bodies	0	0	0	0	0	0	0	0
From Scrub/shrubland	Cropland	0	-4	0	0	0	0	0	0
	Forest	-6	-1013	-144	-342	-498	-223	-353	-1372
	Grassland/other herbaceous vegetation	-50	-236	-171	-793	-410	-470	-725	-1729
	Urban/bare/lightly-vegetated surfaces	-3	-8	-65	-38	-7	-4	0	-1
	Water bodies	0	0	-1	-2	0	0	0	0
To Cropland	Forest	0	1	0	0	187	0	2	0
	Grassland/other herbaceous vegetation	422	138	27	-892	147	272	330	86
	Scrub/shrubland	0	4	0	0	0	0	0	0
	Urban/bare/lightly-vegetated surfaces	0	0	0	0	0	0	0	0
	Water bodies	0	0	0	0	0	0	0	0
From Cropland	Forest	0	0	-53	0	0	0	-2	0
	Grassland/other herbaceous vegetation	-40	-6	0	-75	-20	-34	-13	0
	Scrub/shrubland	0	0	0	0	0	0	0	0
	Urban/bare/lightly-vegetated surfaces	-161	-11	-1	-53	-4	-35	-18	0
	Water bodies	-3	-2	0	-4	0	0	0	0

Table A3-4. Land use class area and area-change (ha) data for each time-step.

Zone	Land Use Classes	Area 1996 (ha)	Area 2001 (ha)	Area 2008 (ha)	Area 2012 (ha)	Area 2018 (ha)	Area-change 1996-2001 (ha)	Area-change 2001-2008 (ha)	Area-change 2008-2012 (ha)	Area-change 2012-2018 (ha)	Area-change 1996-2018 (ha)
Central Waikato	Zone Area	63625	63625	63625	63625	63625	0	0	0	0	0
	Transport/other infrastructure	165	181	211	263	257	16	30	52	-6	92
	Urban area	7553	8463	9100	9170	9708	910	638	70	538	2155
	Cropping/horticulture	1526	1596	1864	1851	1745	69	269	-13	-106	218
	Pastoral grazing	49934	48697	47777	47705	47312	-1237	-920	-72	-393	-2622
	Exotic forestry	471	738	737	720	684	267	-1	-17	-36	213
	Other exotic vegetation	505	508	483	476	473	3	-25	-7	-3	-32
	Indigenous land cover	2859	2829	2837	2819	2818	-30	8	-18	-1	-41
	Water bodies	612	615	616	621	629	3	1	5	8	17
Coromandel	Zone Area	195723	195723	195723	195723	195723	0	0	0	0	0
	Transport/other infrastructure	88	88	106	109	111	0	18	3	2	23
	Urban area	2508	2703	2920	2924	2936	195	217	3	13	428
	Cropping/horticulture	353	357	482	477	477	4	125	-5	0	125
	Pastoral grazing	39252	38115	36955	36900	37005	-1137	-1161	-55	105	-2247
	Exotic forestry	27689	29235	29732	29802	29696	1546	497	70	-106	2007
	Other exotic vegetation	982	587	728	694	695	-395	141	-34	1	-287
	Indigenous land cover	124061	123836	123979	123996	123981	-226	144	17	-15	-81
	Water bodies	384	397	416	416	416	13	19	0	0	32
Lake Taupo	Zone Area	349596	349596	349596	349596	349596	0	0	0	0	0
	Transport/other infrastructure	459	434	448	451	451	-25	14	3	0	-8
	Urban area	2536	2739	3138	3146	3179	202	399	9	33	643
	Cropping/horticulture	350	364	376	376	323	15	12	0	-53	-27
	Pastoral grazing	58910	57256	57207	53710	50741	-1655	-49	-3496	-2969	-8169
	Exotic forestry	66799	68140	67872	71438	74499	1341	-268	3565	3061	7699

	Other exotic vegetation	2662	2696	2795	2827	2825	34	100	32	-2	163
	Indigenous land cover	153870	153926	153732	153619	153547	56	-194	-113	-71	-322
	Water bodies	64010	64042	64028	64029	64030	32	-14	1	2	20
	Zone Area	291172	291172	291172	291172	291172	0	0	0	0	0
	Transport/other infrastructure	900	1144	1438	1439	1437	244	293	2	-2	538
	Urban area	1662	1738	1863	1984	2087	76	125	121	103	425
	Cropping/horticulture	7224	7616	8018	8006	7984	391	402	-11	-22	760
Lower Waikato	Pastoral grazing	210400	207147	206551	206587	206977	-3254	-596	37	389	-3424
	Exotic forestry	11395	14001	14384	14426	14013	2606	382	42	-413	2618
	Other exotic vegetation	10306	10217	9888	9811	9767	-89	-329	-77	-44	-539
	Indigenous land cover	39312	39306	38990	38873	38836	-6	-316	-118	-36	-476
	Water bodies	9972	10003	10040	10045	10070	31	38	5	25	98
	Zone Area	432778	432778	432778	432778	432778	0	0	0	0	0
	Transport/other infrastructure	471	470	464	478	469	-1	-5	13	-8	-2
	Urban area	2311	2348	2446	2548	2598	37	98	102	50	287
	Cropping/horticulture	2115	2241	2426	2425	2425	126	184	0	0	310
Upper Waikato	Pastoral grazing	191684	186105	205701	226355	236743	-5579	19595	20654	10387	45058
	Exotic forestry	172711	178661	158260	137165	126725	5950	-20401	-21095	-10440	-45986
	Other exotic vegetation	3860	3524	3894	4098	3924	-336	370	203	-173	64
	Indigenous land cover	54738	54541	54697	54813	54948	-197	156	117	135	210
	Water bodies	4888	4888	4890	4896	4900	0	3	5	4	12
	Zone Area	394510	394510	394510	394510	394510	0	0	0	0	0
	Transport/other infrastructure	686	756	831	854	864	70	75	23	10	178
	Urban area	4018	4161	4422	4428	4453	144	260	6	25	435
	Cropping/horticulture	3606	3756	3845	3812	3808	149	89	-33	-4	202
	Pastoral grazing	263061	261678	261470	261940	262453	-1383	-208	470	513	-608
	Exotic forestry	24033	25384	25251	25086	24663	1351	-133	-165	-423	630
Waihou Piako											

	Other exotic vegetation	3552	3551	3540	3395	3334	-1	-11	-145	-61	-218
	Indigenous land cover	93502	93146	93043	92894	92831	-356	-104	-149	-63	-671
	Water bodies	2006	2031	2063	2055	2058	25	31	-7	3	52
	Zone Area	306739	306739	306739	306739	306739	0	0	0	0	0
	Transport/other infrastructure	222	226	250	265	265	4	24	15	0	43
	Urban area	2192	2389	2582	2582	2623	197	193	0	41	431
	Cropping/horticulture	1432	1701	1747	1733	1732	269	46	-14	0	300
Waipa	Pastoral grazing	229151	226080	225717	226092	226632	-3072	-363	375	540	-2520
	Exotic forestry	9705	12218	12655	12600	12103	2513	438	-55	-497	2398
	Other exotic vegetation	3568	3613	3369	3137	3112	45	-244	-232	-25	-456
	Indigenous land cover	59609	59645	59544	59454	59396	37	-101	-90	-58	-213
	Water bodies	860	867	875	876	876	7	8	1	0	17
	Zone Area	424911	424911	424911	424911	424911	0	0	0	0	0
	Transport/other infrastructure	88	91	135	173	171	3	44	38	-2	82
	Urban area	704	707	744	744	743	3	36	0	0	39
	Cropping/horticulture	220	286	293	306	306	66	6	13	0	86
West Coast	Pastoral grazing	247419	239725	238128	238473	239102	-7694	-1597	346	629	-8316
	Exotic forestry	14386	21139	23273	23993	23727	6753	2134	721	-266	9341
	Other exotic vegetation	5427	5644	5303	4916	4735	217	-341	-387	-181	-691
	Indigenous land cover	155185	155835	155549	154815	154624	650	-286	-734	-190	-561
	Water bodies	1119	1119	1124	1128	1138	1	5	3	11	20