Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

TECHNICAL REPORT Science Group

Agricultural land use change in mid-Canterbury hill and high country, 1990-2019: implications for indigenous biodiversity and ecosystem health

Report No. R20/62
ISBN 978-1-99-002731-4 (print)
978-1-99-002732-1 (web)

Agricultural land use change in mid-Canterbury hill and high country, 1990-2019: implications for indigenous biodiversity and ecosystem health

Report No. R20/62
ISBN 978-1-99-002731-4 (print)
978-1-99-002732-1 (web)

Philip Grove
Mark Parker
Tina Bayer
Duncan Gray

March 2021

Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

	Name	Date
Prepared by:	*Philip Grove, Mark Parker, Duncan Gray, Tina Bayer*	*November 2020*
Reviewed by:	*Jeromy Cuff*	*December 2020*
External review by:	*Adrian Monks, Manaaki Whenua Landcare Research*	*January 2021*
Approved by:	*Fiona Shanhun Chief Scientist*	*July 2021*

Report No. R20/62
ISBN 978-1-99-002731-4 (print)
978-1-99-002732-1 (web)

200 Tuam Street
PO Box 345
Christchurch 8140
Phone (03) 365 3828
Fax (03) 365 3194

75 Church Street
PO Box 550
Timaru 7940
Phone (03) 687 7800
Fax (03) 687 7808

Website: www.ecan.govt.nz
Customer Services Phone 0800 324 636

Summary

Background

The Canterbury hill and high country has historically experienced less intensive land use compared to the lowland plains. For this reason, it retains relatively natural ecosystems and habitats for indigenous biodiversity, including a range of threatened species. For the same reason, wetlands and waterbodies of the Canterbury high country have historically been healthy and with good water quality, especially again when compared to the state of waterbodies on the low plains.

The problem

Over the last 30 years the Canterbury hill and high country has experienced a significant expansion of area under intensive agricultural land use. As a result, there is concern about impacts on terrestrial biodiversity as well as the health of waterbodies and wetlands in the downstream receiving environment. This land use change and associated concerns have been well documented with respect to the Mackenzie Basin in the upper Waitaki catchment. However, similar pattens of land use change underway in other parts of the region have not been quantified.

What we did

We carried out a desktop GIS assessment of agricultural land use intensification (or pasture conversion) over the period 1990-2019 for the upper Waimakariri, Rakaia, Hakatere/Ashburton and Rangitata catchments.

What we found

Over the period 1990-2019, an additional 6847 ha of undeveloped land or 'semi-improved' pastoral farmland was converted to fully developed farmland, that is high-producing pasture and fodder crops, within our four catchment study areas. Flat or gently sloping landforms, such as the beds and margins of braided rivers, terraces, outwash plains, alluvial fans and moraines, were generally targeted for agricultural development. Most of this post-1990 development was on private freehold land, but pasture conversion of Crown pastoral lease and University of Canterbury lease land was a significant portion of the total. Within our study period this pastoral conversion included direct loss of more than 744 ha of 'Recommended Areas for Protection' (RAPs) identified from ecological surveys in the mid-late 1980s. Some conversion of 'RAPs' had also occurred shortly prior to our study period; total direct loss (to 2019) of identified RAPs within our study area was more than 950 ha.

What does it mean

Hill- and high-country pasture conversion has resulted in direct loss of habitat for indigenous species and probable reduced populations of many species. Ecological impacts of pasture conversion extend beyond the developed areas with fragmentation of and edge effects on adjoining undeveloped indigenous vegetation and habitats for indigenous fauna. There are also adverse effects on wetland and aquatic receiving environments from higher levels of nutrients, sediment and microbial contamination associated with land use intensification.

Consideration of climate change

Whilst climate change was not explicitly considered in this study, the expansion of intensive agricultural land use will also result in increased emission of greenhouse gases, particularly nitrous oxide and methane, relative to previous land use (nil or low intensity grazing).

Table of contents

List of Figures

List of Tables

1 Introduction

Worldwide, agricultural land use is recognised as a significant driver of biodiversity loss and ecosystem degradation (e.g. Cunningham *et al.,* 2013). Loss and degradation result from direct habitat destruction during agricultural development together with adverse effects of subsequent agricultural land use activities on both adjoining undeveloped areas and the downstream receiving environment (Gray, 2018; Saunders *et al.,* 1991).

The vegetation and habitats that support indigenous plant and animal species continue to decline in extent across New Zealand, with agricultural development and exotic forestry the main causes (Cieraad *et al.,* 2015; Monks *et al.,* 2019). For example, from 1996 to 2012, approximately 31,000 ha of tussock grassland, 24,000 ha of indigenous shrubland and 16,000 ha of indigenous forest were cleared across New Zealand (MfE & Stats New Zealand, 2018) in addition to many other areas of habitat for native species. Nationally, this issue has been recognised in the most recent State of Environment Report which describes how land use affects ecosystems and habitats (MfE & Stats New Zealand, 2019).

In the eastern South Island, agricultural land use intensification has been the main driver of habitat loss over the last few decades (e.g. Weeks *et al.,* 2013; Monks *et al.,* 2019). Recent (post-1990) clearance of native vegetation and intensification of agricultural land use, within land that formerly had high biodiversity values, has been facilitated by increasing use of technology such as irrigation and fertilisation. Associated with intensification of agriculture is an increase in the resources (e.g. water, nutrients, agri-chemicals) required to support production, an increase in stocking rate, and consequent increase in leakage of nutrients and contaminants into the surrounding environment (Moller *et al.,* 2008).

The Canterbury Regional Policy Statement contains objectives and policies regarding protection of significant indigenous biodiversity and ecosystems from land use activities. For example, Canterbury Regional Policy Statement (CRPS) Policy 7.3.3 is 'Enhancing freshwater environments and biodiversity'. Policy 9.3.1 states that 'areas identified as significant will be protected to ensure no net loss of indigenous biodiversity or indigenous biodiversity values as a result of land use activities.' Policy 9.3.5(5) is 'to protect adjoining areas of indigenous and other vegetation which extend outside an ecologically significant wetland and are necessary for the ecological functioning of the wetland.' Policy 10.3.2 seeks 'protection and enhancement of areas of river and lake beds and their margins and riparian zones'.

In Canterbury region, agricultural land use change in the upper Waitaki catchment (Mackenzie Basin) has been well documented in numerous studies, plan and consent hearing evidence, and published reports (e.g. Hutchings and Logan 2018; Brower *et al.,* 2018). However, the issue is not confined to the Mackenzie Basin. Other inland or 'high country' parts of the Canterbury Region have experienced similar development pressure.

The purpose of this report is to quantify recent agricultural land use intensification in the hill- and high-country portions of the Waimakariri, Rakaia, Hakatere/Ashburton and Rangitata river catchments of the Canterbury Region. To do this we carried out a Geographic Information System (GIS) based desktop analysis of agricultural land use change in these catchments over the period 1990-2019. Our study is a State of Environment monitoring project, with the focus being on the implications of land use change for indigenous ecosystems and biodiversity of terrestrial, wetland and riparian habitats in this part of the region. However, results could also be of interest in relation to trends in water quality and aquatic ecosystem health, particularly for sensitive receiving environments such as small high-country lakes and spring-fed streams adjoining or downstream of land use change areas.

Lakes in particular can be 'accumulators' of inputs of contaminants such as nutrients and sediment from their catchments, as contaminants can get deposited to the lakebed and/or recycled in the lake ecosystem. Increases in catchment loads of plant macro-nutrients (such as phosphorus and nitrogen) and micro-nutrients (such as trace elements commonly present in commercial fertilisers) to a lake usually results in increased in-lake concentration of these nutrients which in turn can trigger increased algal growth and biomass. Both phytoplankton (free-floating algae) and macrophytes (rooted aquatic plants) are limited in their growth by the availability of nutrients. In many New Zealand lakes phytoplankton tend to be limited by phosphorus (Abell *et al.,* 2010), but the condition of the aquatic macrophyte community is often more strongly influenced by nitrogen than phosphorus (Kelly *et al.,* 2014; Moss *et al.,* 2013). In Canterbury's high-county lakes phosphorus limitation is also more likely that

nitrogen limitation in most lakes (Bayer & Meredith, 2020). Thus, managing inputs of both nitrogen and phosphorus is important for maintaining or improving ecosystem health and services of lakes.

Eutrophication (nutrient enrichment) of lakes can be (usually very slow) natural process but rapid eutrophication is usually linked to human activities (Vollenweider, 1968; Smith, 2003). For instance in a study of 101 lakes in New Zealand high producing grassland (intensive pasture) was the best predictor of in-lake nitrogen and phosphorus concentrations (Abel *et al.,* 2011). Eutrophication often has undesirable effects on lake ecosystems and can limit a lake's 'ecosystem services' (Schallenberg *et al.,* 2013), for instance by decreased visual clarity, changes in species composition, risk of potentially toxic cyanobacterial blooms, decreased suitability as fish habitat, loss of oxygen near lake bed, internal release of nutrients and decreased suitability for human recreation.

2 Methods

2.1 Study areas

Our study areas were the upper catchments of the Waimakariri, Rakaia, Hakatere/Ashburton and Rangitata rivers (Figure 2-1). Note that the 'Upper Rakaia' catchment includes Lake Heron, although this lake is often considered as part of the 'Ashburton Lakes' complex.

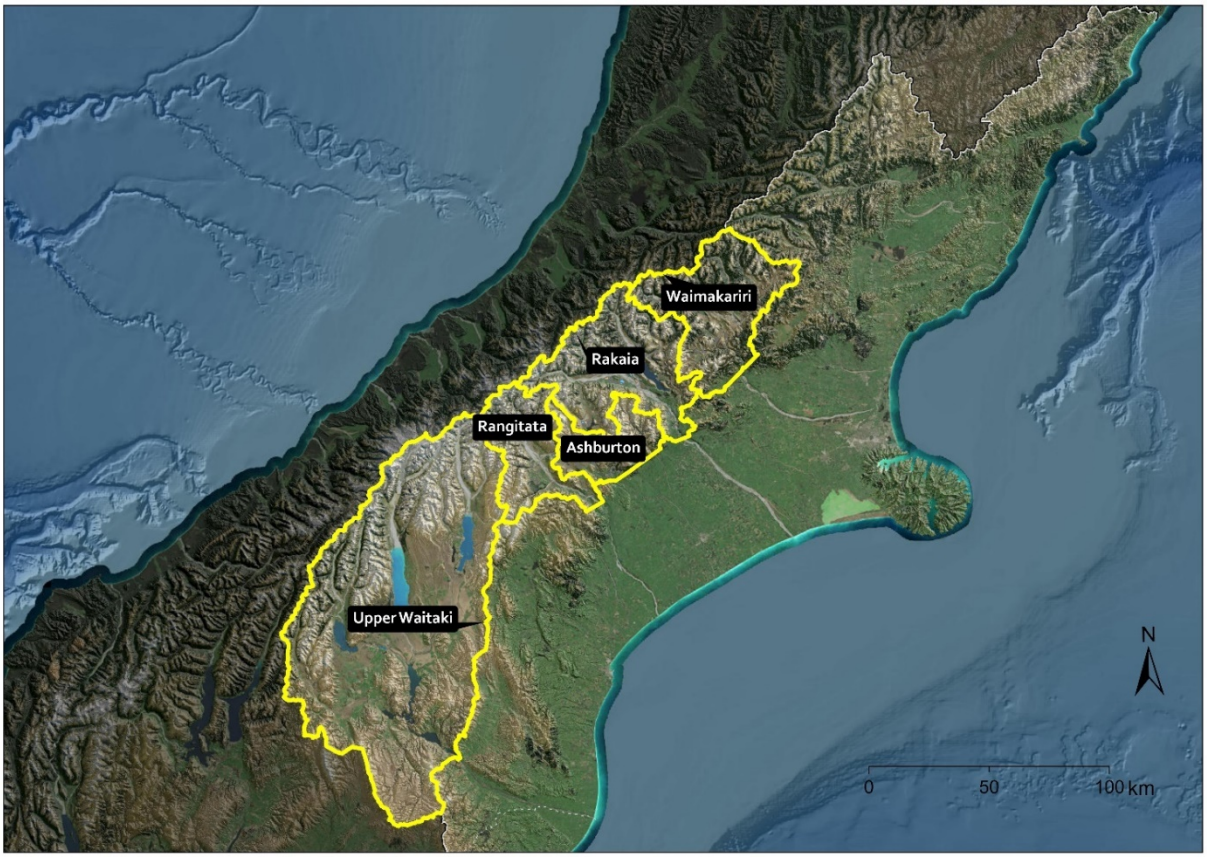

Figure 2-1: Mid/south-Canterbury hill- and high-country study areas: the upper Waimakariri, Rakaia, Hakatere/Ashburton and Rangitata catchments. The upper Waitaki catchment is also shown

2.2 Defining 'land use change'

For the purposes of documenting agricultural land use intensification over the 1990-2019 monitoring interval, our desk-top analysis differentiates between 'developed' and 'undeveloped' pastoral or agricultural land. We defined 'developed' agricultural land as land that has been cleared of its pre-existing vegetation cover and converted to exotic pasture grasses, legumes or fodder crops. Our definition of 'developed' agricultural land in the Canterbury hill- and high-country more-or-less corresponds with the Land cover Database (LCDB) categories of 'High-producing exotic grassland' and 'Short-rotation cropland' (Thompson *et al.,* 2003).

'Undeveloped' land covers a wider spectrum. It can include land that has been, or still is, used for extensive grazing and may in the past have been subject to practices such as regular burning and, more recently, oversowing and topdressing (OSTD). OSTD land was traditionally regarded as 'semi-improved', in contrast to 'unimproved' grazing land (and 'fully improved' or 'developed' land). It was not always possible to distinguish between 'semi-improved' and 'unimproved' land from our desk-top study. And both 'semi-improved' and 'unimproved' land provides habitat for indigenous biota. Therefore, our 'undeveloped' category encompasses both 'semi-improved' and 'unimproved' grazing land. Both typically support a mix of native and exotic plant species in the vegetation as well as indigenous animal and fungal species. 'Undeveloped' land includes vegetation with an intact native canopy, such as grey scrub and tall tussock grassland communities, as well as other vegetation types (e.g. LCDB 'Low producing grassland' and 'Depleted grassland' – Thompson *et al.,* 2003) where exotic plant species may be prominent or even dominant in the vegetation cover.

2.3 Delineating land use change areas

We detected land use change by comparing a 1990 baseline satellite image with more recent satellite and aerial imagery. 'Change areas' were manually delineated using GIS where we observed a change from previous land cover to developed pasture or fodder crop. We used the following visual spectrum satellite imagery to identify, delineate and date land use change within the study catchments:

- Landsat 4 1990
- Landsat 7 2001-2002
- SPOT 5 2006-2008
- SPOT 5 2012
- Sentinel-2 2016-2017
- Sentinel-2 2018-2019

When examining the satellite imagery series, undeveloped areas had a consistent range of colours, without sudden transition to contrasting colours over times. Areas showing change could therefore be 'flagged' by a marked change in colour between two sequential images, although it was not possible to determine the precise nature of the change in vegetation/ground cover from remote imagery. Such marked change in colour between successive satellite images also frequently took the form of geometric shapes together with the obvious colour transition. For example, an undeveloped area that had been cleared and sown in pasture was readily identifiable when the change area was angular or 'paddock-shaped'.

Following initial identification and delineation from recent satellite imagery, 'change areas' were checked, and boundaries refined using high-resolution aerial imagery. After initial mapping, progressively older satellite and aerial imagery was viewed so that 'change areas' could be dated. Aerial imagery viewed was from Environment Canterbury's digital library. These collections are mosaics compiled at different times over different parts of the region. The main region-wide aerial imagery mosaics we used were dated:

- 2004-2010
- 2010-2015
- 2016-2019

In addition to the listed satellite and aerial imagery, the time slider function in 'Google Earth Pro' was also used, where possible, to record the date of observed change more precisely. Visual cues to timing

of land use change included removal of woody vegetation, removal of native tussock grasses, newly bare (cultivated or sprayed) paddocks, newly sown paddocks, installation of irrigation systems. While species composition of vegetation pre- and post- conversion could not be determined from aerial imagery, we could readily identify major changes in vegetation structure (e.g. from shrubland to grassland) and conversion to cropland and pasture.

Changes from 'undeveloped' to 'developed' agricultural land were mapped in ArcGIS Pro for four time periods: 1990-2000; 2001-2008; 2009-2012; 2013-2019. An example of a mapped change area is shown in Figures 2-2 and 2-3 below.

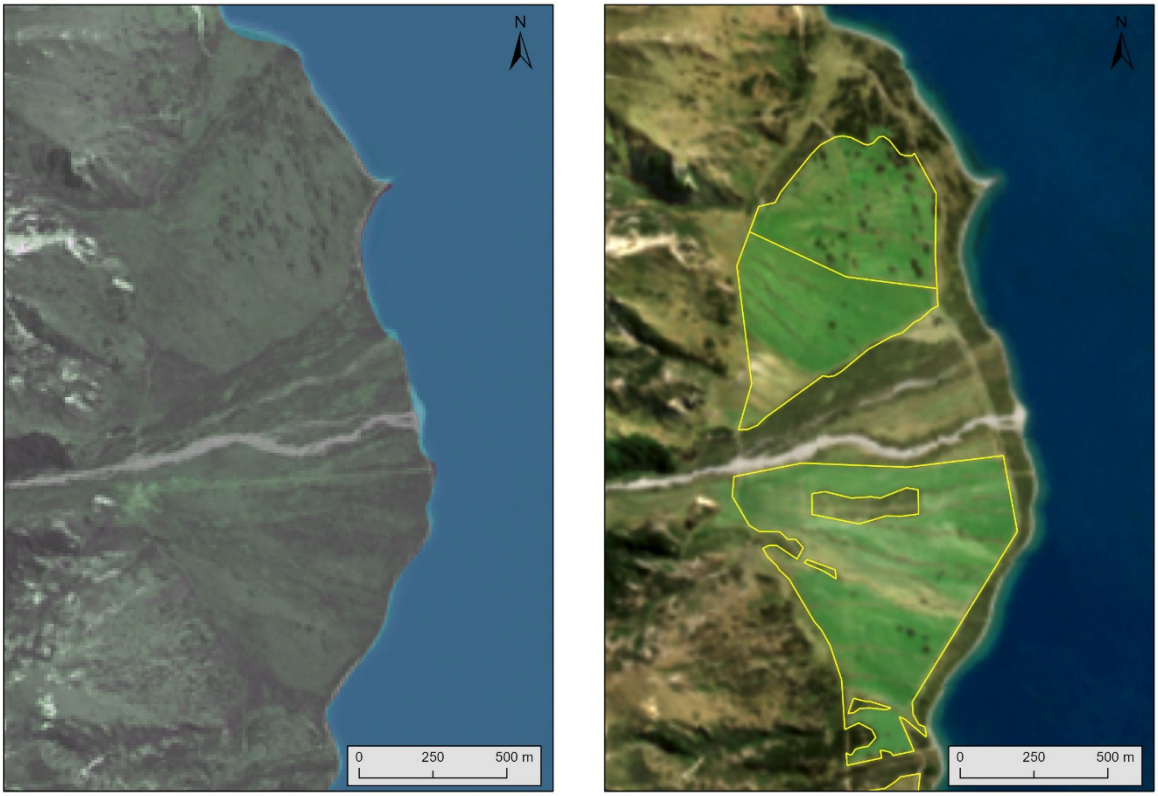

Figure 2-2: Example of change areas: polygons (yellow lines) in the upper Rakaia catchment mapped from comparison of 2012 Landsat 7 satellite imagery (left) and 2018-19 Sentinel satellite imagery (right)

Figure 2-3: Example of change areas: polygons (yellow lines) in the upper Rangitata catchment mapped from comparison of 2008 aerial imagery (left) and 2012 aerial imagery (right)

2.4 Categorising land use change areas by landform

We used the Glacial Geomorphological Landforms geodatabase prepared by Geological and Nuclear Sciences (GNS) to categorise land use change areas by landform (Barrell *et al.,* 2011). The GNS geodatabase covered all our study areas except for part of the Two Thumb Range on the southern margin of the Upper Rangitata catchment.

All mapped change areas were covered by the Glacial Geomorphic Landforms geodatabase. Geodatabase landforms intersected by our mapped change areas were aggregated into eight broader landform categories, with advice from Associate Professor Peter Almond (Soil and Physical Sciences Department, Lincoln University). The aggregation is shown in Table 2-1.

Table 2-1: Glacial Geomorphic Landforms from the GNS geodatabase (left column) that intersected mapped change areas, and broader aggregate landforms used in this study (right column). (Note that the GNS geodatabase does also identify a range of non-glacial landforms)

latest Late Otiran moraine Late Otiran moraine latest Late Otiran moraine ridge Early Otiran or older moraine Late Otiran moraine ridge Kettle hole	Moraines
latest Late Otiran outwash surface Late Otiran outwash surface Late Otiran alluvial plain or terrace Early Otiran or older outwash surface Holocene outwash plain or terrace Early Otiran or older alluvial plain or terrace	Glacial outwash surfaces
Holocene alluvial plain or terrace	Modern outwash surfaces or plains
Ice-sculpted bedrock surface General bedrock terrain Fluvial channel in bedrock Ice-trimmed bedrock slope	Bedrock terrain
Active river plain	River bed
Holocene alluvial fan latest Late Otiran alluvial fan Late Otiran alluvial fan Early Otiran or older alluvial fan	Alluvial fans
Steep eroded slope in Quaternary deposits Gully Landslide terrain	Hillslopes
latest Late Otiran beach Swamp or abandoned lake bed Lake, pond, estuary or lagoon Holocene beach ridge or beach plain Holocene lake bed	Wetlands, waterbodies and littoral zones

2.5 Recommended areas for protection

We intersected land use change areas mapped in our study catchments against publicly available digitised maps of 'Recommended Areas for Protection' (RAPs) previously identified and described in Protected Natural Areas Programme survey reports for the Cass, Craigieburn and Coleridge ecological districts (Shanks *et al.,* 1990); Mathias and Mt Hutt ecological districts (Arand and Glenny, 1990); and the Arrowsmith and Hakatere ecological districts (Harrington *et al.,* 1986). The Protected Natural Areas Programme survey reports provided comprehensive ecological descriptions of RAPs. These assessments were completed shortly before the start of our study period.

The ecological districts surveyed and described in these reports collectively covered most of our study area (Figure 2-4).

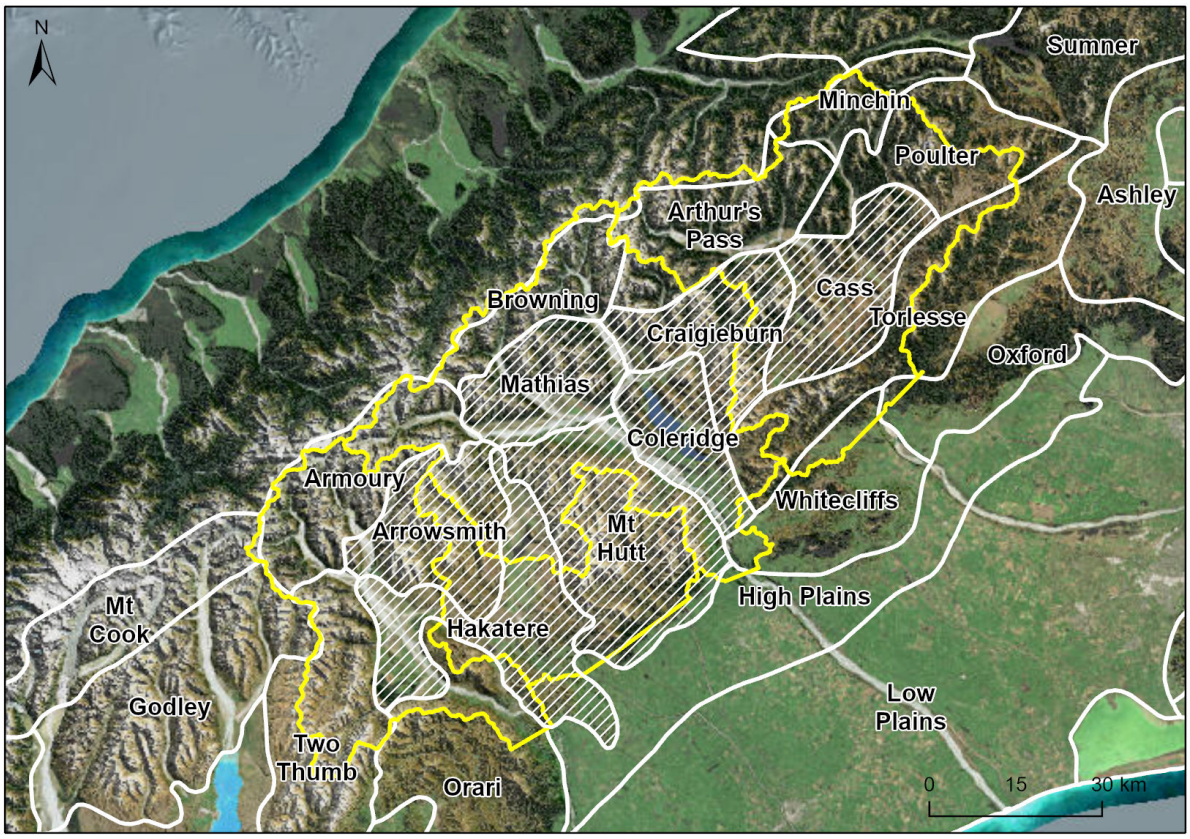

Figure 2-4: Ecological districts (McEwen *et al.,* 1987) within the upper Waimakariri, Rakaia, Hakatere/Ashburton and Rangitata catchment study areas. Surveyed ecological districts referred to in this study are shown in white cross-hatch

2.6 Land tenure

Change areas were assessed against land tenure information as shown on the Environment Canterbury GIS cadastral layer in May 2020. The cadastral layer is updated quarterly using Land Information New Zealand (LINZ) data.

2.7 Potentially developable land area

We also calculated approximate extent of potentially 'developable' land within each study catchment, based on the key parameters of elevation and slope. For purposes of this analysis we considered land above 900 m, as well as lakes and active riverbeds below 900 m, as not 'developable'. Below 900 m, we applied two slope thresholds - <10 degrees and <20 degrees – to provide two estimates of potentially developable land extent in each study catchment. Land tenure was not a factor in this assessment.

We used the Canterbury 8 m Digital Elevation Model (DEM) sourced from Environment Canterbury's GIS. We clipped the DEM to our catchment study areas using the 'Clip Raster' tool and used the 'Con' tool to separate land areas above and below 900 m. We then used the 'Slope' tool within the clipped (<900 m) catchment study areas to identify slopes under 10 degrees and under 20 degrees. The 'Tabulate Area' was run to calculate total extent of land under 900 m and within the two slope range scenarios. Extent of lakes and active braided riverbeds, from the Environment Canterbury lakes GIS layer and the riverbed habitat analysis of Pompei *et al.* (2019) respectively, were subtracted to provide final calculations of 'potentially developable land area' in each study catchment.

3 Results

3.1 Location and extent of land use change areas

Extent of agricultural land-use change over the period 1990-2019 is summarised in Table 3-1 below. The figures show the sum of areas converted from 'undeveloped' land to 'fully developed' farmland, that is high-producing exotic pasture and fodder crops. Table 3-2 and Figure 3-1 show extent of developed agricultural land up to 1990 compared with extent of developed land in 2019 for the four study catchments.

Areas targeted for agricultural development tend to be flat or gently sloping landforms such as the beds and margins of braided rivers, terraces, outwash plains, alluvial fans and moraines (Table 3-3). While our observations were that most hill- and high-country pasture conversion took place on flat to gentle (<10˚) slopes, we also recorded examples of pasture conversion on moderate-grade hillslopes (10˚-20˚), particularly in the upper Rakaia catchment. However, because pasture conversion of moderate-grade hillslopes was of relatively limited extent overall, we applied the <10˚ slope threshold for our estimate of extent of 'potentially developable land' in each study catchment (Table 3-4).

Table 3-1: Summed extent of agricultural land use change (ha) in four Canterbury hill-and high-country catchment areas, 1990-2019

Catchment	Summed land use change areas (ha)				
	1990-2000	**2001-2008**	**2009-2012**	**2013-2019**	**Total 1990-2019**
Waimakariri	0	47	166	926	1139
Rakaia	222	276	2230	1189	3918
Hakatere/Ashburton	339	213	184	334	1069
Rangitata	75	8	173	465	721
Total	**636**	**544**	**2753**	**2914**	**6847**

Table 3-2: Summed extent of developed agricultural land in four Canterbury hill-and high-country catchment areas, pre-1990 and in 2019

Catchment (total area in ha)	Developed land 1990 (ha)	Developed land 2019 (ha) and % increase on 1990
Waimakariri (233623 ha)	1985 ha	3124 ha (57%)
Rakaia (261058 ha)	15652 ha	19570 ha (25%)
Hakatere/Ashburton (101563 ha)	6546 ha	7615 ha (16%)
Rangitata (147191 ha)	5294 ha	6015 ha (14%)
Total (743444 ha)	29477 ha	36324 ha (23%)

Our analysis did not identify any examples of reversion from developed farmland to undeveloped land or native vegetation over the study period.

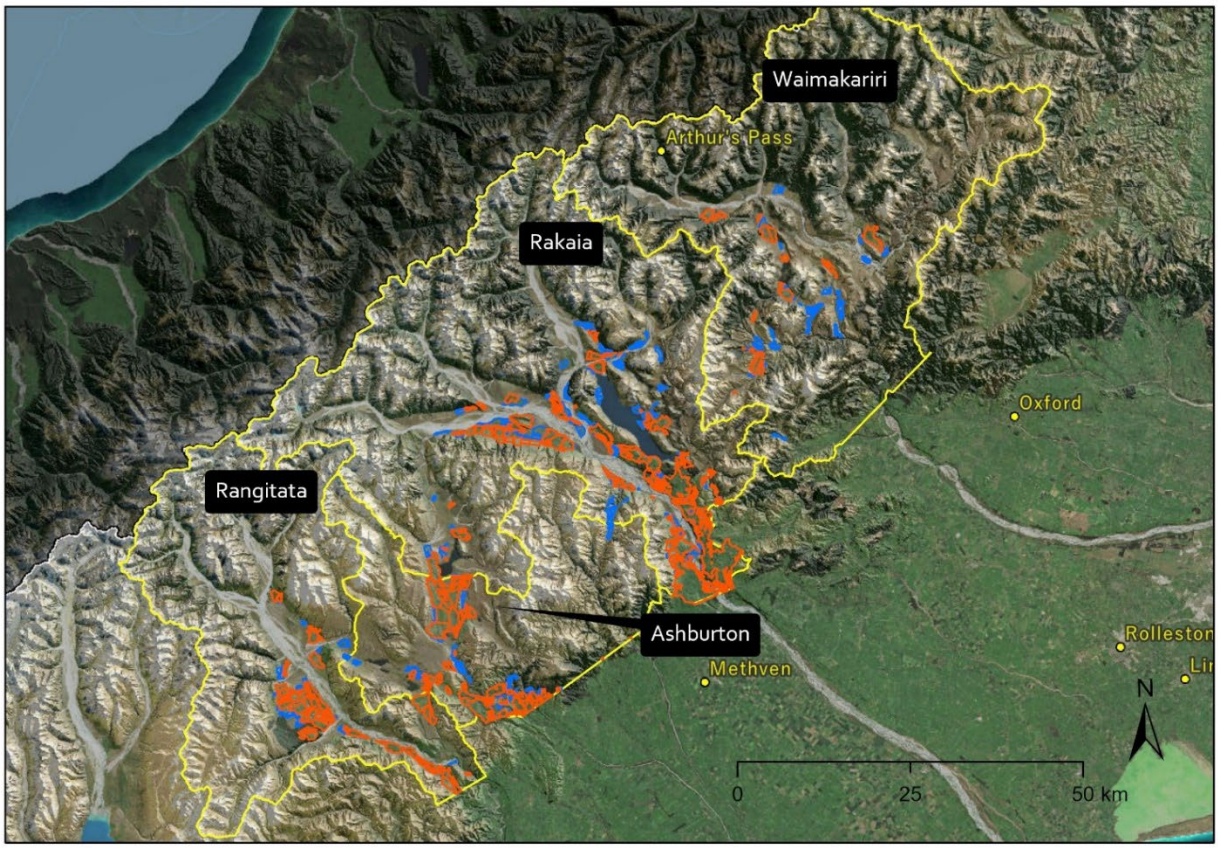

Figure 3-1: Upper Waimakariri, Rakaia, Ashburton and Rangitata catchment study areas (yellow outlines) showing location and extent of developed agricultural land in 1990 (orange outlines), with additional development up to 2019 (blue outlines)

Table 3-3: Summed extent of agricultural land use change (ha) by landform in four Canterbury hill-and high-country catchment areas, 1990-2019

Landform	Waimakariri	Rakaia	Hakatere/ Ashburton	Rangitata	Total
Alluvial fans	267 ha	1002 ha	221 ha	181 ha	1671 ha
Bedrock terrain	53 ha	116 ha	176 ha	0	345 ha
Glacial outwash surfaces	516 ha	182 ha	267 ha	63 ha	1028 ha
Hillslopes	18 ha	97 ha	7 ha	3 ha	125 ha
Modern outwash surfaces or plains	5 ha	1651 ha	69 ha	53 ha	1778 ha
Moraines	257 ha	786 ha	259 ha	413 ha	1715 ha
River bed	23 ha	50 ha	53 ha	8 ha	134 ha
Wetlands, waterbodies and littoral zones	0	34 ha	17 ha	0	51 ha
Total	1139 ha	3918 ha	1069 ha	721 ha	6847 ha

Location of land use change areas within each study catchment are shown in more detail in Figures 3-2 – 3-5.

Table 3-4: Estimated extent of 'potentially developable' land in four hill- and high-country catchment areas; and proportion of this developed pre-1990 and by 2019

Catchment	Potentially developable land area (ha)	Proportion developed 1990 (%)	Proportion developed 2019 (%)
Upper Waimakariri	26956	7%	12%
Upper Rakaia	40351	39%	48%
Upper Hakatere/Ashburton	18645	35%	41%
Upper Rangitata	16021	33%	38%
Total	101613	29%	36%

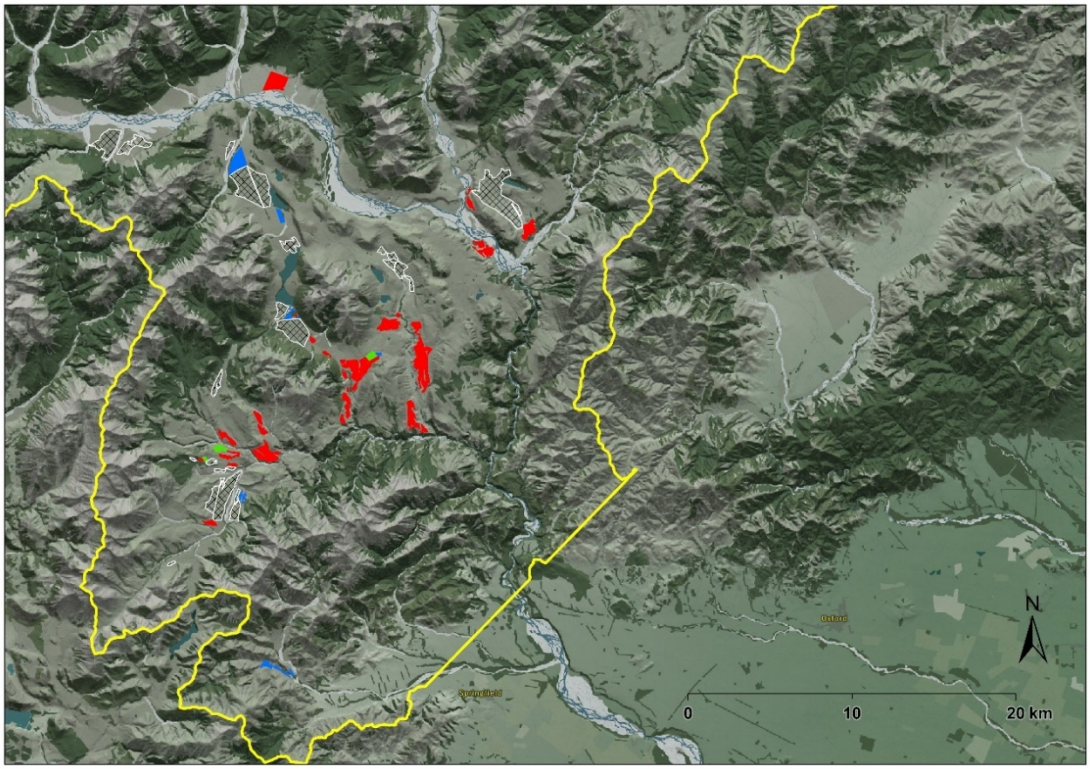

Figure 3-2: Location of agricultural land use intensification 'change areas' 1990-2019 in the upper Waimakariri River catchment (yellow outline). Green indicates 2001-2008; blue 2009-2012; red 2013-19. There was no change 1990-2000. Black & white hatch are pre-1990 developed areas

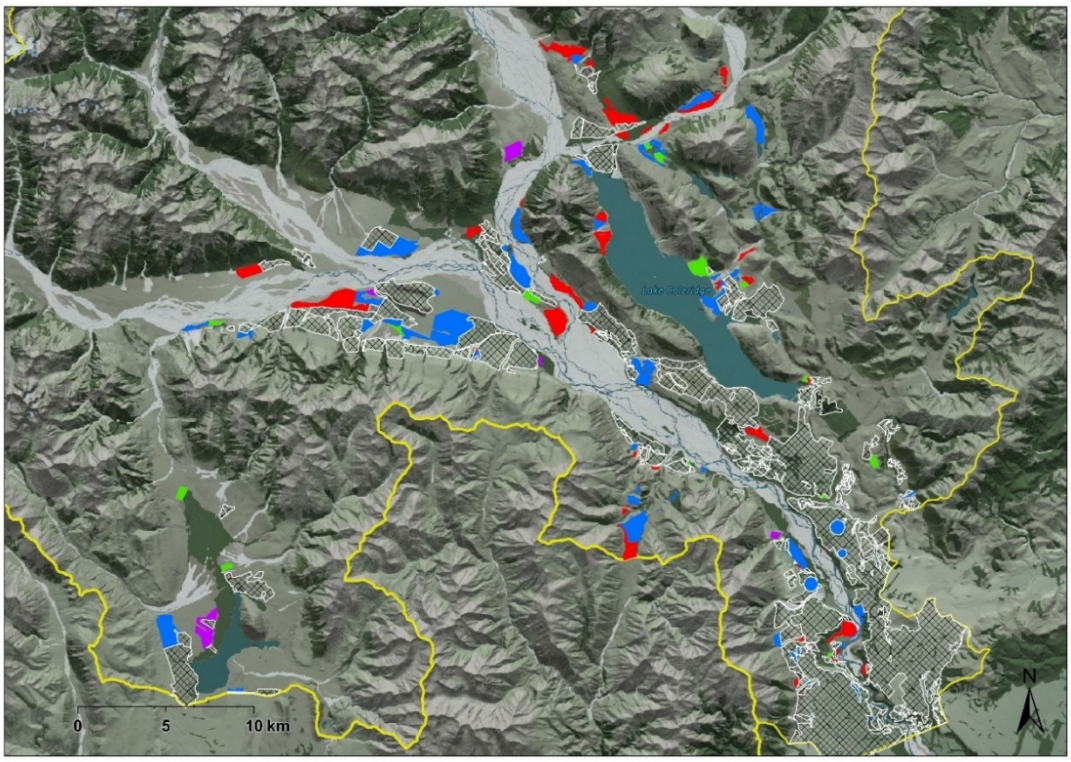

Figure 3-3: Location of agricultural land use intensification 'change areas' 1990-2019 in the upper Rakaia River catchment (yellow outline). Purple indicates 1990-2000; green 2001-2008; blue 2009-2012; red 2013-19. Black & white hatch are pre-1990 developed areas

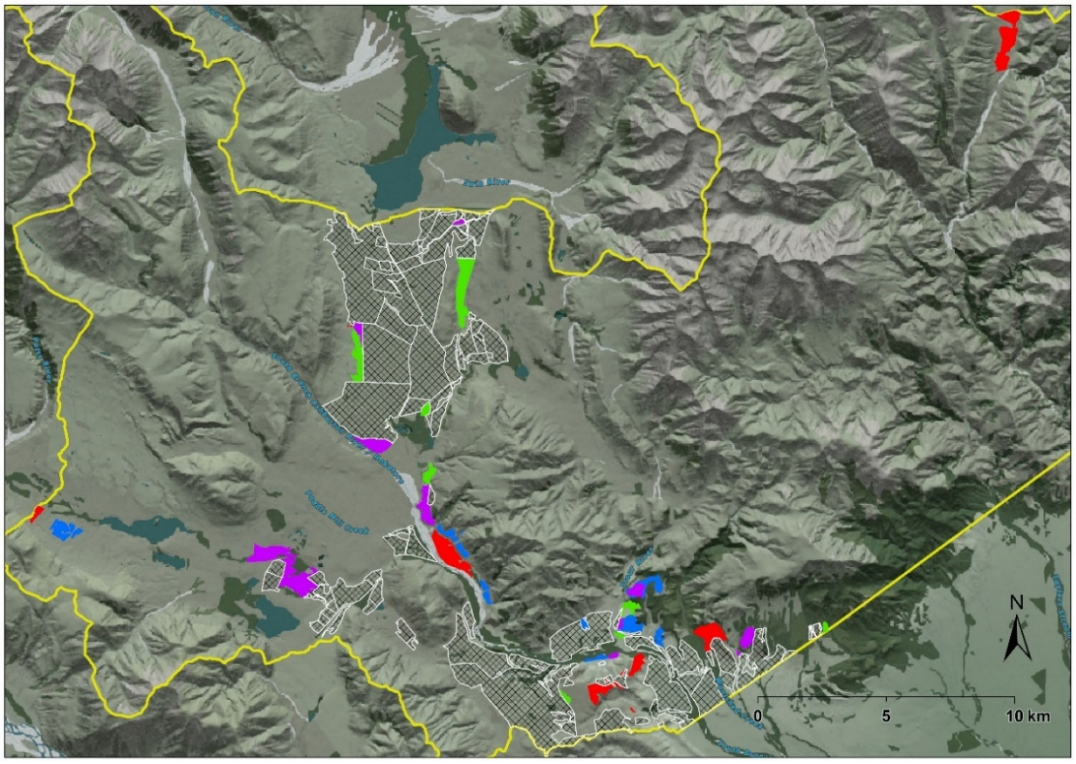

Figure 3-4: Location of agricultural land use intensification 'change areas' 1990-2019 in the upper Ashburton River catchment (yellow outline). Purple indicates 1990-2000; green 2001-2008; blue 2009-2012; red 2013-19. Black & white hatch are pre-1990 developed areas

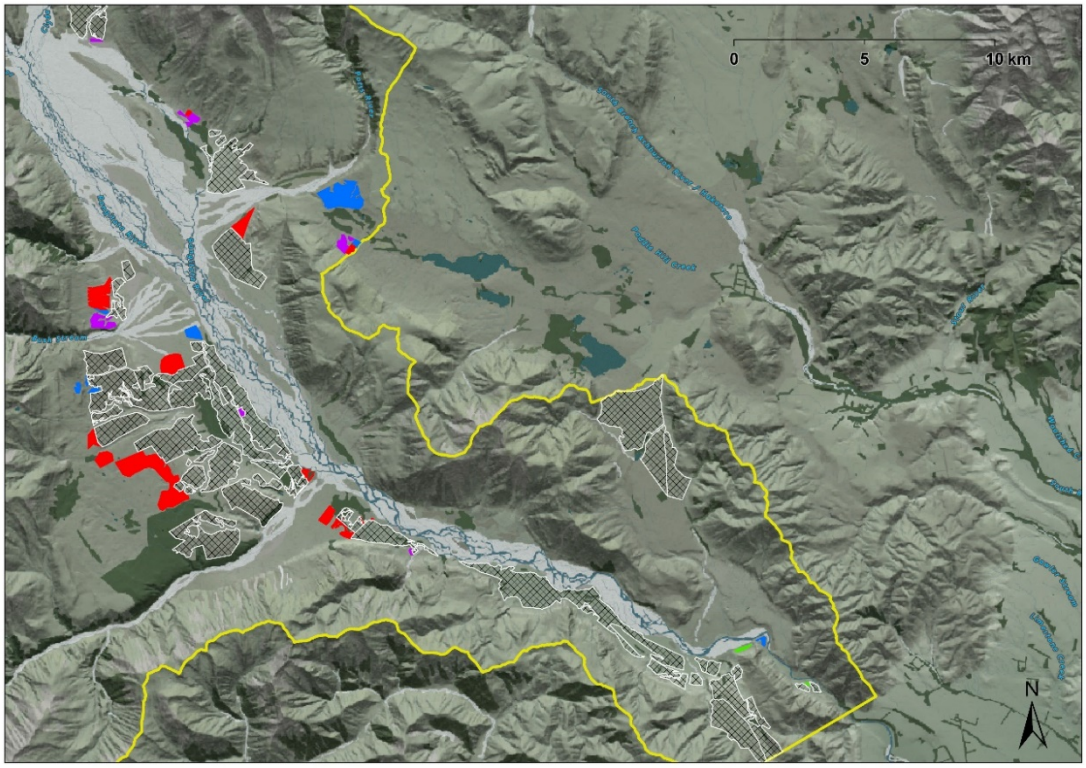

Figure 3-5: Location of agricultural land use intensification 'change areas' 1990-2019 in the upper Rangitata River catchment (yellow outline). Purple indicates 1990-2000; green 2001-2008; blue 2009-2012; red 2013-19. Black & white hatch are pre-1990 developed areas

Within the upper Waimakariri catchment study area (total 233,623 ha), post 1990 development has been concentrated on glacial outwash surfaces, moraines and alluvial fans (Figure 3-2, Table 3-3). The upper Waimakariri catchment has seen the greatest % increase in area of developed agricultural land of our four study areas compared to the 1990 baseline (Table 3-2). The upper Waimakariri is also distinctive in that most of this new development has taken place within the 2013-19 monitoring interval (Table 3-1). However, the proportion of 'developable' land that has been developed remains the lowest of the four study areas, increasing from 7% in 1990 to 12% in 2019 (Table 3-4). Post 1990 agricultural development in this catchment has taken place on University of Canterbury lease land, private freehold and Crown Pastoral lease (CPL) land (Table 3-5).

The Upper Rakaia catchment has seen the greatest total area of agricultural development since 1990 (3918 ha) of the four study catchments. Most (2230 ha) occurred in the 2009-2012 period, but there has also been substantial (1189 ha) new development over the most recent 2013-2019 monitoring interval. This development has been concentrated along modern outwash surfaces adjoining the Rakaia, Wilberforce, Harper and Mathias Rivers (1700 ha; Figure 3-3), as well as on alluvial fan and moraine landforms (Table 3-3). Tenure of land developed since 1990 is mostly private freehold and CPL, with smaller areas of Unalienated Crown Land (UCL) or hydro parcels also developed (Table 3-5).

While the Upper Rakaia catchment showed the greatest total area of new development, the % increase since 1990 was only 25%, because this catchment already contained substantial areas of developed land. However, the pre-1990 development was concentrated at the lower/downstream end of the catchment, whereas most of the post-1990 development has taken place further inland (Figure 3-3). We estimate that of the 'potentially developable' land area in this catchment, the proportion of land that is actually developed has increased from 39% in 1990 to 48% in 2019; the highest of our four study catchments.

The upper Hakatere/Ashburton catchment saw 1069 ha of new agricultural development from 1990-2019, a 16% increase on the 1990 developed area (Table 3-2). Substantial areas of the 'basin' between

Lake Heron and Lake Emma had already been developed by 1990. Some new development occurred on the glacial outwash surfaces and moraines within the main basin, but much of the development, particularly in the later 2009-2012 and 2013-19 monitoring intervals, was on modern outwash surfaces along the margins of the Hakatere/Ashburton River South Branch, and alluvial fans in the lower/eastern section of the catchment. A distinctive, isolated site of recent agricultural development in the catchment was at Cookies Flat in the headwaters of the Swift River, a tributary of the North Hakatere/Ashburton (Figure 3-4).

We estimate that about 35% of the low-altitude and low relief land in the upper Hakatere/Ashburton catchment had been developed by 1990, this had increased to 41% by 2019. Across the catchment, tenure of post-1990 developed land was mostly private freehold with some CPL (Table 3-5).

The upper Rangitata catchment showed 721 ha of agricultural development from 1990-2019, a 14% increase on the pre-1990 developed area of 5294 ha. Most of this new development was on moraine (413 ha) and alluvial fan (181 ha) landforms and took place in the later 2008-12 and 2013-19 monitoring intervals of our study period (Figure 3-5). Proportion of developed low-altitude, low-relief land in the catchment increased from 33% in 1990 to 38% by 2019. Tenure of developed land was mostly private freehold, with some CPL also affected (Table 3-5).

Table 3-5: Tenure of land developed for agriculture in four Canterbury hill-and high-country catchments, 1990 – 2019

	Waimakariri	Rakaia	Hakatere/ Ashburton	Rangitata	Total
Private freehold	260	2166	996	670	4092
Crown pastoral lease	111	1697	73	47	1928
University of Canterbury lease	768	8			776
Unalienated Crown Land / Hydro parcel		42		3	45
Department of Conservation		5		1	6
Total	1139 ha	3918 ha	1069 ha	721 ha	6847 ha

3.2 Recommended areas for protection

In the period 1990-2019, 13 Recommended Areas for Protection (RAPs), identified in surveys of the Cass, Coleridge, Mathias, Mt Hutt, Arrowsmith and Hakatere ecological districts, were directly impacted by agricultural development (existing vegetation cover over more than 10 ha or more than 10% of their area converted to developed pasture or fodder crops). In total, 744 ha within these 13 RAPs in our study area were converted to high-producing pasture or crops over the period 1990-2019.

The ‘Cass Flats’ RAP was completely cleared of its short tussock grassland and matagouri vegetation cover in the period 2009-2012. Approximately 85% of ‘Redcliffe Saddle’ RAP was converted to high-producing pasture between 2014-2016. Other RAPs saw a smaller, but still substantial, % reduction in area: ‘Redoubt’ (16%), ‘Glenrock Swamp’ (26%), ‘Big Ben Swamp’ (42%) and ‘Māori Lakes’ (13%) (Table 3-6).

Table 3-6: Recommended areas for protection with more than 10 ha or 10% of their area directly impacted by pasture conversion, 1990-2019

RAP name and ID number	Area and % of RAP impacted	Impacted habitat and vegetation types
Cass Flats (Cass 13)	44 ha (100%)	River floodplain with short tussock grassland, scattered matagouri shrubs.
Rakaia Gorge and terraces (Coleridge 1)	34 ha (6.5%)	Montane mixed broadleaved forest and shrubland; silver tussock grassland.
Ryton Gorge (Coleridge 21)	10 ha (4%)	Braidplain vegetation, short tussock grassland and herbfield.
Ryton Lakes (Coleridge 22)	47 ha (3.5%)	Short tussock grassland on outwash, red tussock grassland on terrace riser.
Mt Oakden (Coleridge 29)	59 ha (5.2%)	Native shrubland on fan.
Redoubt (Coleridge 26)	8 ha (16%)	Red tussock grassland adjoining wetland.
Big Ben Swamp (Coleridge 17)	13 ha (42%)	Red tussock grassland on hillslope, adjoining wetland.
Glenrock Swamp (Mathias 2)	8 ha (26%)	Mixed native-exotic shrubland and rough pasture on river flats adjoining wetland.
Palmer Range (Mt Hutt 3)	93 ha (6%)	Short tussock grassland and matagouri shrubland on hillslope.
Redcliffe Saddle (Mt Hutt 15)	195 ha (85%)	Short tussock grassland, red tussock grassland, bog rush tussockland, matagouri shrubland, cotton daisy herbfield.
Lake Stream-Cameron Fan-Lake Heron (Hakatere 2)	155 ha (4.5%)	Short tussock grassland and matagouri shrubland on fan adjoining wetland.
Māori Lakes (Hakatere 6)	24 ha (13%)	Short tussock grassland adjoining lakes and wetlands.
Upper Ashburton (Hakatere 10)	54 ha (8%)	Matagouri-mixed shrubland on terrace risers; snow tussock grassland and short tussock grassland on river terraces.

The ecological surveys on which these Protected Natural Areas Programme reports were based all took place in the mid-to-late 1980s. Another five RAPs described from Coleridge, Mathias and Hakatere Ecological Districts had been directly impacted before 1990, with a total affected area of 223 ha (Table 3-7).

Table 3-7: Recommended areas for protection with more than 10 ha or 10% of their area directly impacted by pasture conversion since survey, pre-1990

RAP name and ID number	Area and % of RAP impacted	Impacted habitat and vegetation types
Coleridge Downs Lakeside (Coleridge 20)	13 ha (54%)	Native scrub, shrubland, tussock grassland and wetland on hill slopes and valley floor.
Coleridge Downs Tarns (Coleridge 14)	80 ha (58%)	Moraine landform with kettlehole tarns, short tussock grassland, matagouri shrubland.
Coleridge Road Swamps (Coleridge 12)	35 ha (51%)	Harakeke, pukio swamp vegetation with native shrubland on margins
Double Hill (Mathias 1)	29 ha (56%)	Native shrubland on roche moutonee landform.
Deep Stream (Hakatere 18)	66 ha (70%)	Spring-fed tributary on Rangitata flood plain. Riparian margin wetland vegetation and tussock grassland converted to pasture.

Table 3-8 lists a further 28 RAPs within the study areas where agricultural development has occurred up to their margins.

Table 3-8: Recommended areas for protection that have been developed up to their margins

RAP name and ID number	RAP name and ID number
Broken River limestone (Cass 2)	Hutt Stream fan (Mt Hutt 7)
Waimakariri River gorge (Cass 5)	Mount Somers (Mt Hutt 10)
Lake Pearson (Cass 10)	Rakaia Faces Forest Remnants (Mt Hutt 14)
Acheron Gorge (Coleridge 9)	Redcliffe Hill (Mt Hutt 15)
Coalmine Swamp (Coleridge 10)	South Ragged Range (Mathias 10)
Mt Barker tarns (Coleridge 11)	Totara Creek (Mathias 11)
Blackhole Dam (Coleridge 15)	Twin Creek Fan (Mathias 12)
Big Ben Roche Moutonnee (Coleridge 16)	Wilberforce Riverbed (Mathias 13)
Acheron Hill (Coleridge 18)	Rangitata River (Hakatere 21)
Mt Georgina (Coleridge 20)	Alford Range (Mt Hutt 1)
Rakaia Riverbed (Coleridge 30)	Lake Emma (Hakatere 12)
Lake Coleridge (Coleridge 31)	Emily (Hakatere 5)
Hydra Waters-Chimera Fan (Mathias 3)	Lake Denny (Hakatere 22)
Martello Swamp (Mathias 6)	Erewhon beech remnants (Arrowsmith 4)

The fate of documented RAPs described in Tables 3-6 – 3-8 addresses only ‘the best of what remained’ within the surveyed ecological districts, and not native vegetation or habitats for indigenous fauna generally. It therefore underestimates effects of agricultural intensification on indigenous vegetation and habitats in the wider study area.

Figures 3-6 – 3-9 show some paired (before and after) examples of identified change areas. In all cases the bright green areas in the later images are newly-cultivated pasture or forage crops.

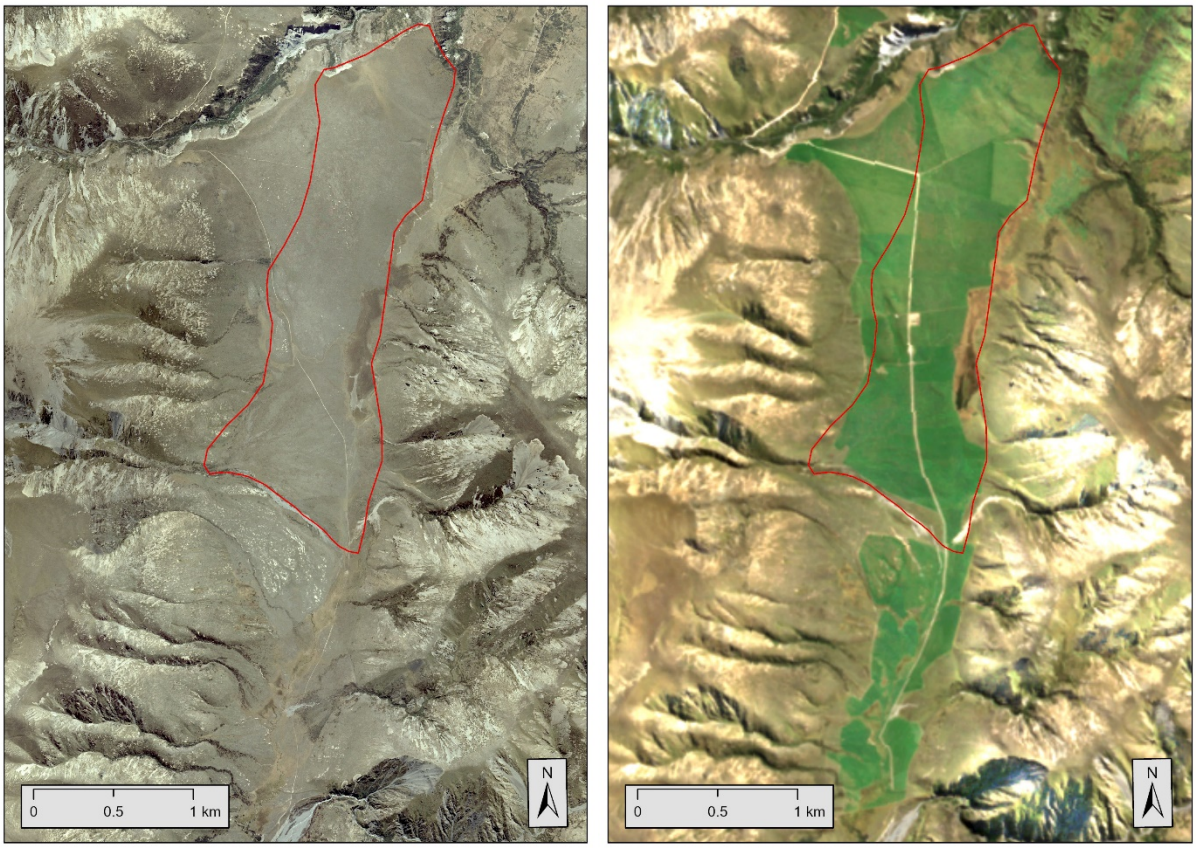

Figure 3-6: Development at Cookies Flat-Redcliffe Saddle (900 m) straddling the boundary between Rakaia and Ashburton catchments. 2008 aerial photograph on left; 2018-19 satellite imagery on right. The red outline delineates the 'Redcliffe Saddle' Recommended Area for Protection (Arand and Glenny 1990). Bright green areas are the 'change areas' of cultivated pasture developed over the period 2014-16

Figure 3-7: Agricultural development south of the Harper River in and around 'Ryton Lakes' Recommended Area for Protection (red outline - Shanks *et al.,* 1990). 2006 aerial photograph on left; 2018-19 satellite imagery on right. Bright green areas north of the road are cultivated pasture

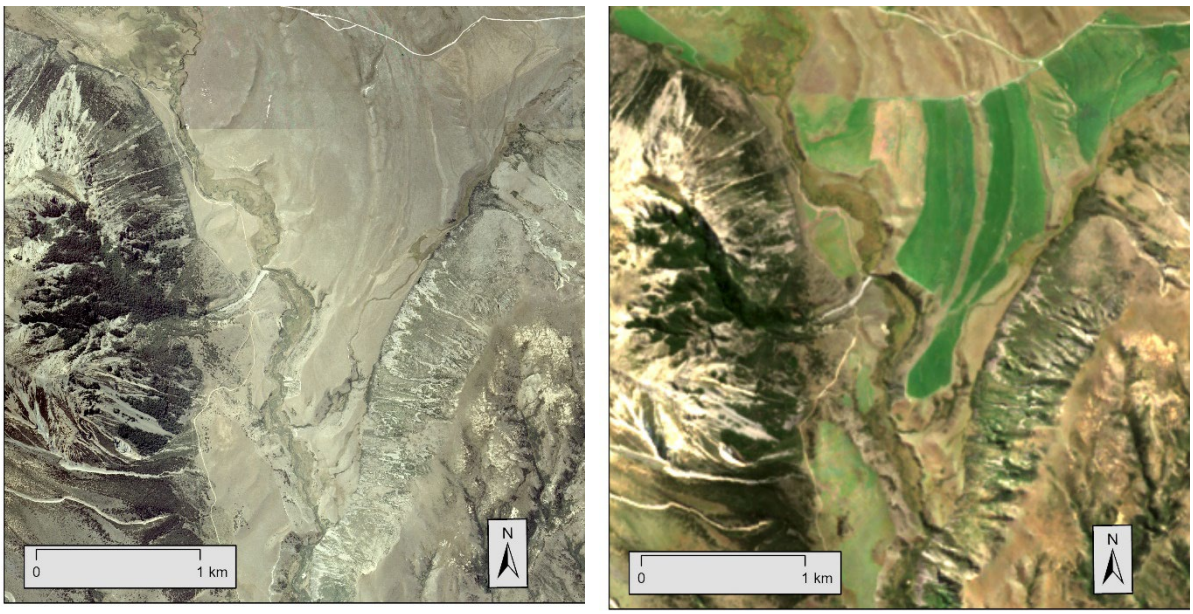

Figure 3-8: Agricultural development of terraces overlooking Winding Creek, upper Waimakariri catchment. 2006 aerial photograph on left; 2018-19 satellite imagery on right

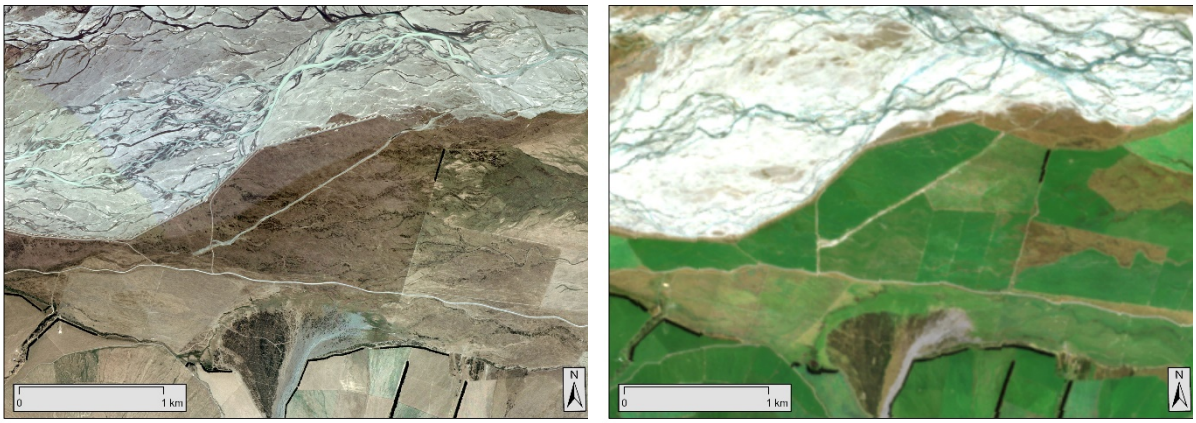

Figure 3-9: Agricultural development around Double Hill Stream, upper Rakaia catchment. 2006 aerial photograph on left; 2018-19 satellite imagery on right

Figure 3-10: Agricultural development of flats on the south side of Potts River, upper Rangitata catchment. 2004 aerial photograph on left; 2018-19 satellite imagery on right

4 Discussion

Across four hill- and high-country catchment study areas, we recorded a 6847 ha expansion of developed agricultural land over the period 1990-2019, a 23% increase on the 1990 baseline. These results are consistent with and complementary to other studies looking at the ongoing clearance of indigenous vegetation and habitats for indigenous species across the eastern South Island (e.g. Walker *et al.,* 2006; Weeks *et al.,* 2013; Cieraad *et al.,* 2015; Brower *et al.,* 2018).

Areas targeted for agricultural development tend to be flat or gently sloping landforms such as the beds and margins of braided rivers, terraces, outwash plains, alluvial fans and moraines. We estimate that the proportion of low-altitude (<900 m), low-slope (<10˚) terrain developed across the four study areas increased from 29% in 1990 to 36% by 2019. However, the extent of such conversion in the upper Waimakariri catchment (from 7% in 1990 to 12% by 2019) is far less than for the other three catchments: the upper Rakaia (from 39% in 1990 to 48% by 2019); upper Hakatere/Ashburton (from 35% to 41%); and upper Rangitata (from 33% to 38%).

It is clear from much of the aerial imagery, as well as from existing ecological information and our own observations, that agricultural development has resulted in widespread loss of indigenous vegetation and habitats of indigenous fauna. The progressive clearance of identified Recommended Areas for Protection (RAPs – 'the best of what remains' of indigenous vegetation and habitats) described nationally by Monks *et al.* (2019) was also observed in our study areas, where more than 960 ha of RAPs described from ecological surveys in the mid- to late 1980s have been cleared and converted since those surveys.

Indigenous vegetation clearance and agricultural development in these catchments is ongoing. Beyond the 2019 close-off date of this study for example, we have observed firstly on Google Earth and then on follow-up site visits further clearance of native dry shrubland vegetation and cultivation / direct drilling of native or semi-native short tussock grassland and mossfield-herbfield vegetation on Canterbury University lease properties in the upper Waimakariri catchment.

4.1 Comparison with upper Waitaki studies

The areal extent of conversion to high-producing pasture and fodder crops recorded for the upper Waimakariri, Rakaia, Hakatere/Ashburton and Rangitata catchments recorded in this study is considerably less than for the upper Waitaki. For example, Brower *et al.* (2018) found that in less than 15 years (2003-2017) the area of intensive agricultural land use in the Mackenzie Basin more than doubled in size, with approximately 25,000 ha growth of intensification.

The upper Waitaki catchment has a far greater area of flat and gently sloping landforms (glacial and fluvial outwash plains and moraine landforms) particularly targeted for pasture conversion than our study catchments put together. We estimate the extent of such land below 900 m in the upper Waitaki catchment at 220,215 ha, compared with a total of 101,613 ha for our study catchments. The proportion of this land developed in the upper Waitaki (using figures from Brower *et al*. 2018) has increased from 9% in 2003 to 20% by 2017. The availability of water for irrigation that was formerly allocated for hydro-electric power generation has been a key factor in the rapid and widespread land use change taking place in this part of the region.

The rate and extent of land use change in the upper Waitaki catchment over the last two decades has been larger than that of other parts of the Canterbury high-country. However, if we consider the extent of 'potentially developable' low-altitude and low-slope landforms, the proportion of such land converted to high producing pasture and fodder crops in the upper Rakaia, Ashburton and Rangitata catchments has, as of 2019, actually been considerably greater than for the upper Waitaki.

4.2 Comparison with national Land Cover Database

The thematic and spatial resolutions of the national Land Cover Database (LCDB) are too low to describe local or paddock-scale changes in indigenous cover and habitat for indigenous species

(Dymond *et al*., 2017; Monks *et al.,* 2019). Nevertheless, at the larger catchment or regional scale, LCDB trends are consistent with results of this and other studies describing land use change in the Canterbury high country over the last 20-30 years. For the same upper Waimakariri, Rakaia, Hakatere/Ashburton and Rangitata catchment areas described in this study, LCDB shows over the period 1996 (LCDB1) to 2018 (LCDB5) a *c.* 4,874 ha increased extent of 'High Producing Exotic Grassland' and 'Short Rotation Cropland, as well as a 2,418 ha increase of exotic forest. This was countered by a substantial reduction in extent of 'Low Producing Grassland' (6473 ha) together with *c.* 1,200 ha total reduced extent of the following native vegetation covers: 'Matagouri or grey scrub', 'Manuka and kanuka', 'Fernland', 'Indigenous Forest' and 'Tall Tussock Grassland'.

4.3 Effects on indigenous biodiversity and ecosystems

4.3.1 Terrestrial ecosystems

Results of this and comparable studies describe the conversion of undeveloped land to developed agricultural land by area. This conversion has immediate implications in terms of habitat loss for indigenous species, particularly those of threatened dryland ecosystems. Low-relief terrain of Canterbury's inland basins falls within dryland environments characterised by cold winters, strong winds, warm summers and semi-arid annual precipitation. Almost all remaining undeveloped (i.e. uncultivated and unirrigated) vegetation on low-relief landforms (e.g. fluvial and glacial outwash surfaces, alluvial fans, moraines) is significant indigenous vegetation and/or habitat for indigenous fauna because of the extent of past loss and concentration of threatened and at-risk species in what remains. Even severely degraded sites can meet Canterbury Regional Policy Statement ecological significance criteria where they provide habitat for threatened species (Walker *et al.,* 2019).

The Threatened Environments Classification (TEC) provides a national-level assessment of how much of the full range of terrestrial natural ecosystems remain and are protected from loss. A revision of the classification by Cieraad *et al.* (2015) found that since the first iteration (Walker *et al.,* 2006), there was a trend of more protection in environments with historically high levels of indigenous vegetation and protection, such as alpine tussock grassland and forest ecosystems, but less indigenous vegetation and protection in low-relief lowland-montane areas than estimated in the previous version of the TEC. Our results are consistent with this.

Beyond the straight-forward metric of loss of habitat area itself however, it is difficult to quantify the implications of habitat loss for populations of indigenous species. One useful indicator, though, is the conservation status of native plants. Canterbury has the highest number of threatened and at-risk plant species of any New Zealand botanical region, and a high proportion of these occur in the high-country dryland zone (Walker *et al.,* 2019). The effect of habitat loss on populations of indigenous plant species is reflected in their changed conservation status in the latest Department of Conservation threat rankings (de Lange *et al.,* 2018). Species such as matagouri (*Discaria toumatou*), *Carex buchananii* and scabweed (*Raoulia australis*) that were previously considered 'not threatened' and widespread in the Canterbury hill and high country are now listed as 'At Risk: Declining'. Others, such as *Muehlenbeckia ephedroides* and *Raoulia monroi*, have shifted from 'At Risk' to 'Threatened' in their conservation status.

For indigenous fauna populations, effects of habitat loss can be difficult to distinguish from effects of introduced predators. Nevertheless, studies of indigenous lizards provide examples of where loss and fragmentation of habitats are reducing the distribution of formerly widespread species and putting some populations at risk of local extinction (Frank and Wilson, 2011). Sparsely vegetated glacial outwash surfaces and modern outwash surfaces of Canterbury inland basins are important breeding habitat for migratory banded dotterel (*Charadrius bicinctus bicinctus*). O'Donnell and Monks (2020) consider that habitat loss and degradation, as well as predation and other disturbance pressures, is contributing to the substantial decline in banded dotterel populations over recent decades described in their recent study.

Agricultural land use intensification also has adverse, although less immediate, effects on remaining terrestrial indigenous habitats adjacent to developed areas. Studies to measure these 'cross boundary', 'off site' or 'edge' effects of agricultural land use on New Zealand terrestrial ecology have been limited to date. A small number of studies have been carried out in lowland Canterbury (e.g. Ecroyd and Brockerhoff 2005; Bowie *et al.,* 2016; Walker, 2020) and elsewhere in New Zealand (e.g. Didham *et al.,*

2015). Walker (2020) also provides some initial results from recently-established study sites in the Mackenzie Basin. There is, however, an extensive body of overseas research documenting a range of edge effects from irrigation and other agricultural practices on terrestrial ecosystems. Walker *et al.* (2019), in a review of local and overseas ecological literature on this issue, summarised as follows:

- The process of land clearance leaves indigenous vegetation in fragmented patches across landscapes and brings indigenous vegetation into direct contact with land under more intensive use at the human-induced edge.
- Environmental conditions (e.g. humidity, temperature, hydrology, wind) are altered near the edges of indigenous vegetation, and abiotic contaminants (e.g. dust, water, fertiliser, herbicide, insecticide) and disturbances can move or 'spill over' across boundaries and onto adjacent land.
- Biological incursions also occur, including weeds, pests, stock, green waste and pathogens.

Over time, these changes and incursions can lead to marked alterations in the biological character (composition, diversity and functioning) of the affected indigenous vegetation. Spillover of water and/or nutrients from adjacent agricultural land to naturally dry or low-nutrient systems disadvantages native plant species (Peltzer *et al.,* 2016) and has the potential to modify adjacent ecosystems by facilitating exotic plant invasions and lowering native species diversity (Walker, 2020). Within our study area, agricultural land use intensification has occurred up to the boundaries of or into 31 RAPs. We therefore anticipate adverse cross-boundary effects on these RAPs as well as other remaining indigenous vegetation and habitats for indigenous fauna as a result.

4.3.2 Aquatic and wetland ecosystems

By contrast, cross boundary or off-site effects of land use intensification on aquatic and wetland habitats are well-documented in the scientific literature, both for New Zealand generally (Moller *et al.,* 2008), and for Canterbury region hill and high country (e.g. Gray, 2018; Bayer and Meredith, 2020).

Land use intensification results in the introduction to the environment of several contaminants, a change to hydrological processes and direct damage to and loss of aquatic habitats. Sediment, faecal contaminants, and nutrients such as phosphorus and nitrogen can run off the land during rainfall or enter water directly when stock access streams. Fine sediment in particular, has considerable impacts on low gradient spring fed streams and their aquatic communities (Burdon *et al*., 2013; Greenwood *et al*., 2012). Run off and stock access contaminants can be mitigated with appropriate riparian management. However, nitrogen is highly soluble in water and tends to leach into soil and shallow groundwater eventually reaching streams and wetlands. Nitrogen may be the limiting nutrient for the growth of plants and excessive quantities result in eutrophication, changes in community structure and loss of ecological values (Allan & Castillo, 2007). A study of streams in the Canterbury High country found that shifts in macroinvertebrate communities along a land use intensification gradient were most closely correlated with nitrogen concentrations, suggesting these streams are highly sensitive to even slight increases in nitrogen (Gray, 2018).

Drainage of wetlands, stream diversion, re-alignments, piping and other activities that alter stream flow and associated hydrological-ecological processes are commonly associated with the intensification of land use (Gray and Burge, 2018). On the lowland plains of Canterbury there has been a progressive loss of aquatic habitat and values to facilitate agricultural efficiency. Land use intensification in the high country, if un-regulated, is likely to result in similar outcomes.

4.4 Alignment with regional objectives and policies

The Canterbury Regional Policy Statement contains objectives and policies regarding protection of significant indigenous biodiversity and ecosystems from land use activities. For example, Canterbury Regional Policy Statement (CRPS) Policy 7.3.3 is 'Enhancing freshwater environments and biodiversity'. Policy 9.3.1 states that 'areas identified as significant will be protected to ensure no net loss of indigenous biodiversity or indigenous biodiversity values as a result of land use activities.' Policy 9.3.5(5) is 'to protect adjoining areas of indigenous and other vegetation which extend outside an ecologically significant wetland and are necessary for the ecological functioning of the wetland.' Policy 10.3.2 seeks 'protection and enhancement of areas of river and lake beds and their margins and riparian zones'.

Based on our results, it appears that District and Regional Council planning and regulatory processes have failed to implement these objectives and policies. Terrestrial ecosystems and indigenous biodiversity of the Canterbury hill and high country have not been adequately protected from effects of agricultural land use intensification. In addition, we have seen examples of other management agencies - Land Information New Zealand and the Department of Conservation – giving approval to pastoral lessees for clearance of native vegetation and farm development without regard for RMA (District and Regional Council) requirements. Both the direct loss, to agricultural development, of thousands of hectares of ecologically significant vegetation and habitats for indigenous fauna that have occurred across inland Canterbury over the last 30 years, and associated indirect or cross-boundary effects on remaining indigenous ecosystems have been largely unmitigated.

Councils' planning and regulatory measures have also failed to protect sensitive aquatic and wetland receiving environments from spillover or cross boundary effects of intensified land use. For example, most of Canterbury's high-country lakes are located in scheduled 'Sensitive Lake Zones' in the Canterbury Land and Water Regional Plan, which sets tighter controls on activities in their catchments. However, water quality in about a third of the small to medium-sized Canterbury high-country lakes monitored by Environment Canterbury is deteriorating, as concentrations of nitrogen, phosphorus or algal biomass are increasing. In addition, two-thirds of these lakes exceed objectives and limits set in the Canterbury Land and Water Regional Plan for their trophic (nutrient) state (Bayer & Meredith, 2020). Most of the lakes for which plan objectives are not met are located in the Ashburton Lakes Basin (upper Ashburton and Rakaia catchments) or the Upper Waimakariri catchment; both areas identified in this report as being affected by changes in agricultural land use.

Impacts of land use change on biodiversity and ecosystems in the upper Waitaki catchment, particularly the Mackenzie Basin, have received considerable attention from the media and NGOs over recent years, and have received some response from national, regional and local government agencies. However, the same patterns of land-use intensification and associated adverse environmental effects in other parts of Canterbury have received less attention. The need for better agency alignment and a coordinated response identified by Hutchings and Logan (2017) with respect to the Mackenzie Basin also applies to other parts of the Canterbury hill and high country.

5 Conclusion

Over the period 1990-2019, pasture conversion of more than 6800 ha of hill and high-country land in the upper Waimakariri, Rakaia, Haketere/Ashburton and Rangitata catchments has resulted in direct loss of habitat for indigenous species and probable reduced populations of many species. Flat or gently sloping landforms, such as the beds and margins of braided rivers, terraces, outwash plains, alluvial fans and moraines, were generally targeted for agricultural development. Most of the post-1990 development was on private freehold land, but pasture conversion of Crown pastoral lease and University of Canterbury lease land formed a significant proportion (*c.* 40%) of the total. This pastoral conversion included direct loss, within our study period, of more than 744 ha of 'Recommended Areas for Protection' (RAPs) identified from ecological surveys in the mid-late 1980s. Some conversion of 'RAPs' had also occurred shortly prior to our study period; total direct loss (to 2019) of identified RAPs within our study area was more than 950 ha.

Ecological impacts of pasture conversion extend beyond the developed areas, with fragmentation of and edge effects on adjoining undeveloped indigenous vegetation and habitats for indigenous fauna. There are also adverse effects on wetland and aquatic receiving environments from higher levels of nutrients, sediment and microbial contamination associated with land use intensification.

Agricultural land use intensification is ongoing. This suggests that a more coordinated approach and better alignment between management agencies is still required to deliver on national and regional objectives for the maintenance and protection of biodiversity, ecosystem health and natural character.

6 Acknowledgements

Thanks to Mark Davis for assistance with GIS data capture and Peter Almond for geomorphology advice. We greatly appreciate the very helpful review comments on this report from Jeromy Cuff (Environment Canterbury) and Adrian Monks (Manaaki Whenua Landcare Research).

7 References

Abell J.M., Oezkundakci, D., & Hamilton, D.P. (2010). Nitrogen and Phosphorus limitation of phytoplankton growth in New Zealand lakes: Implications for eutrophication control. *Ecosystems*, *13*(7), 966–977. https://doi.org/10.1007/s10021-010-9367-9

Abell J.M., Özkundakci, D., Hamilton, D.P., & Miller, S.D. (2011). Relationships between land use and nitrogen and phosphorus in New Zealand lakes. *Marine and Freshwater Research*, *62*(2), 162–175. https://doi.org/10.1071/MF10180

Allan J.D, Castillo M.M. 2007. *Stream Ecology: Structure and Function of Running Waters*. Second. Dordrecht: Springer.

Arand J. and Glenny D. 1990: Mathias and Mt Hutt Ecological Districts. Protected Natural Areas Programme Survey Report 12. Department of Conservation, Wellington. 248 p.

Barrell D.J.A., Andersen B.G., Denton G.H. 2011. Glacial geomorphology of the central South Island, New Zealand. GNS Science monograph 27. 81 p + map (5 sheets) + legend (1 sheet). Lower Hutt, New Zealand. GNS Science.

Bayer, T., & Meredith, A. (2020). Canterbury high-country lakes monitoring programme – state and trends, 2005-2019. Environment Canterbury Technical Report, Report No. R20/50.

Bowie M.H., Black L., Boyer S., Dickinson N.M., Hodge S. 2016. Persistence of biodiversity in a dryland remnant within an intensified dairy farm landscape. *New Zealand Journal of Ecology 40(1)*: 121-130.

Brower A.L., Sprague R., Vernotte M., McNair H. 2018. Agricultural intensification, ownership, and landscape change in the Mackenzie Basin. *Journal of New Zealand Grasslands 80:* 47-54.

Burdon F.J., McIntosh A.R., Harding J.S. 2013. Habitat Loss Drives Threshold Response of Benthic Invertebrate Communities to Deposited Sediment in Agricultural Streams. *Ecological Applications* 23 (5): 1036–47. https://doi.org/10.1890/12-1190.1.

Cieraad E., Walker S., Price R., Barringer J. 2015. An updated assessment of indigenous cover remaining and legal protection in New Zealand's land environments. *New Zealand Journal of Ecology 39*: 309-315.

Cunningham S.A., Attwood S.J., Kamal S.B., Benton T.G., Broadhurst L.M., Didham R.K., McIntyre S., Perfecto I., Samways M.J., Tscharntke T., Vandermeer J., Villard M-A, Young A.G., Lindenmayer D.B. 2013. To close the yield-gap while saving biodiversity will require multiple locally relevant strategies. *Agriculture, Ecosystems and Environment 173*: 20-27.

de Lange P.J., Rolfe J.R., Barkla J.W., Courtney S.P., Champion P.D., Perrie L.R., Beadel S.M., Ford K.A., Breitweiser I., Schönberger I., Hindmarsh-Walls R., Heenan P.B, Ladley K. 2018. *Conservation status of New Zealand indigenous vascular plants, 2017*. Department of Conservation, Wellington, New Zealand.

Didham R.K., Barker G.M., Bartlam S., Deakin E.L., Denmead L.H., Fisk L.M., Peters J.M., Tylianakis J.M., Wright H.R., Schipper L.A. 2015. Agricultural intensification exacerbates spillover effects on soil biogeochemistry in adjacent forest remnants. PLoS One 10: e0116474.

Dymond J.R., Shepherd J.D., Newsome P.F, Bellis S. 2017. Estimating change in areas of indigenous vegetation cover in New Zealand from the Land Cover Database (LCDB). *New Zealand Journal of Ecology 41(1):* 55-64.

Ecroyd C.E., Brockerhoff E.G. 2005. Floristic changes over 30 years in a Canterbury Plains kanuka forest remnant, and comparison with adjacent vegetation types. *New Zealand Journal of Ecology 29*: 279-90.

Frank H. and Wilson D.J. 2011. Distribution, status and conservation measures for lizards in limestone areas of South Canterbury, New Zealand. *New Zealand Journal of Zoology 38:1*: 15-28.

Gray D. 2018. High country spring-fed streams: effects of adjacent land use. Environment Canterbury Report No. R18/32.

Greenwood M.J., Harding J.S., Niyogi D.K., McIntosh A.R. 2012. Improving the Effectiveness of Riparian Management for Aquatic Invertebrates in a Degraded Agricultural Landscape: Stream Size and Land-use Legacies. *Journal of Applied Ecology* 49: 213–22.

Kelly, D., Robertson, H., & Allen, C. (2014). Nutrient loading to Canterbury high- country lakes for sustaining ecological values. Cawthron Report NO. 2557. Prepared for Department of Conservation and Environment Canterbury, (2557), 77.

Harrington W.M.A., Cooper P.T., Davis C.M., Higham T.D., Mason C. 1986. Heron Ecological Region: survey report for the Protected Natural Areas Programme. New Zealand Protected Natural Areas Programme No 4. Department of Lands and Survey, Wellington. 214 p.

Hutchings J. and Logan H. 2017. Mackenzie Basin. Opportunities for agency alignment. Report prepared for the project steering group. HenleyHutchings, Wellington. January 2018.

McEwen W.M. 1987. Ecological regions and districts of New Zealand. 3rd rev. edn. Department of Conservation, Wellington.

Ministry for the Environment & Stats NZ 2018. *New Zealand's Environmental Reporting Series: Our land 2018.* Retrieved from www.mfe.govt.nz and www.stats.govt.nz. Published in April 2018 by Ministry for the Environment and Stats NZ. Publication number: ME 1350.

Ministry for the Environment & Stats NZ 2019. New Zealand's Environmental Reporting Series: *Environment Aotearoa 2019*. Available from www.mfe.govt.nz and www.stats.govt.nz. Published in April 2019 by Ministry for the Environment and Stats NZ. Publication number: ME 1416.

Moller H., MacLeod C.J., Haggerty J., Rosin C., Blackwell G., Perley C., Meadows S., Weller F., Gradwohl M. 2008. Intensification of New Zealand agriculture: implications for biodiversity. *New Zealand Journal of Agricultural Research 51: 253-263*.

Monks A., Hayman E., Walker S. 2019. Attrition of recommended areas for protection: clearance of ecologically significant vegetation on private land. *New Zealand Journal of Ecology 43(2)*: 3367

Moss, B., Jeppesen, E., Søndergaard, M., Lauridsen T.L., Liu Z. 2013. Nitrogen, macrophytes, shallow lakes and nutrient limitation: resolution of a current controversy? *Hydrobiologia, 710(1):* 3-21. http://dx.doi.org/10.1007/s10750-012-1033-0

O'Donnell, C.F.J., Monks J.M. 2020. Distribution, long term population trends and conservation status of banded dotterels (*Charadrius bicinctus bicinctus*) on braided rivers in New Zealand. *Notornis 67(4)*: 733-753.

Peltzer D.A., Kurokawa H., Wardle D.A. 2016. Soil fertility and disturbance interact to drive contrasting responses of co-occurring native and non-native species. *Ecology 97*: 515-529.

Pompei M., Grove P., Cuff J. 2019. Monitoring extent of available habitat for indigenous braided river birds in Canterbury – a 2012 baseline. Environment Canterbury Report No. R18/14.

Saunders D.A., Hobbs R.J., Margules C.R. 1991. Biological consequences of ecosystem fragmentation: a review. *Conservation Biology 5*: 18-32.

Schallenberg M, de Winton M.D., Verburg P., Kelly D.J., Hamill K.D., Hamilton D.P. 2013. Ecosystem services of lakes. In Dymond JR ed. Ecosystem services in New Zealand– conditions and trends. Manaaki Whenua Press, Lincoln, New Zealand.

Shanks A., Glenny D., Gibson R., Rosser K., Roozen D., Phillipson S., Steven J., Arand J. 1990. Coleridge, Craigieburn and Cass Ecological Districts. Protected Natural Areas Programme Survey Report 10. Department of Conservation, Wellington. 306 p.

Smith, V. H. (2003). Eutrophication of freshwater and coastal marine ecosystems: A global problem. Environmental Science and Pollution Research 10, 126-139

Thompson S., Gruner I., Gapare N. 2003. New Zealand Land Cover Database Version 2. Illustrated Guide to Target Classes. Ministry for the Environment, Wellington.

Vollenweider, R. A. (1968). 'Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors of eutrophication.' Organisation for Economic Co-operation and Development, Paris, France.

Walker S. 2020. Measured edge effects on indigenous grassland and shrubland vegetation on low-relief topography in Canterbury. Manaaki Whenua – Landcare Research Contract Report LC3866. 63 pp.

Walker S., Brownstein G., Monks A. 2019. Avoiding cross-boundary effects of agricultural land use on indigenous dryland habitats in the Canterbury Region: consenting guidelines and planning recommendations. Manaaki Whenua – Landcare Research Contract Report LC3636. 63 pp.

Walker S., Price R., Rutledge D., Stephens R.T.T., Lee W.G. 2006. Recent loss of indigenous cover in New Zealand. *New Zealand Journal of Ecology 30(2):* 196-177.

Weeks E.S., Walker S., Dymond J.R., Shepherd J.D. and Clarkson B.D. 2013. Patterns of past and recent conversion of indigenous grasslands in the South Island, New Zealand. *New Zealand Journal of Ecology 37(1)*:127-138.

Environment Canterbury Regional Council
Kaunihera Taiao ki Waitaha

Facilitating sustainable development in the Canterbury region

ecan.govt.nz