New Zealand Fluvial and Pluvial Flood Exposure

Prepared for The Deep South Challenge

Prepared by:
Ryan Paulik
Heather Craig
Daniel Collins

For any information regarding this report please contact:

Ryan Paulik
Hazard Analyst
Meteorology and Remote Sensing
+64-4-386 0601
ryan.paulik@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
Private Bag 14901
Kilbirnie
Wellington 6241

Phone +64 4 386 0300

NIWA CLIENT REPORT No: 2019118WN
Report date: June 2019
NIWA Project: DEPSI18301

Quality Assurance Statement		
	Reviewed by:	Dr Emily Lane
	Formatting checked by:	Patricia Rangel
	Approved for release by:	Dr Andrew Laing

Contents

Tables

Executive summary

This study is a first attempt to enumerate New Zealand's populations and asset exposure in fluvial and pluvial floodplains.

- A national and consistent flood hazard map for New Zealand is absent at an appropriate resolution for identifying populations and assets in fluvial and pluvial floodplains. In the absence of a national flood hazard map, exposed areas are identified by creating a 'composite' flood hazard area map (FLHA) from modelled and historic flood hazard maps and flood prone soil maps, publicly available in August 2018. The map represents known or mapped floodplains and was deemed sufficient for a first attempt at enumerating national, region and territory level population and asset exposure.

- This report uses the term "elements at risk" to include: population, buildings (number and 2016 NZD replacement value), transport infrastructure (roads, railways, airports), electricity infrastructure (transmission lines, structures, sites), three-waters infrastructure (nodes, pipelines), and land cover (built, production, natural or undeveloped). These elements at risk provide a representative sample of built assets and land cover types exposed within New Zealand's fluvial and pluvial floodplains. Elements at risk were identified on land within the FLHA. An overview of elements at risk in the FLHA are presented national and regional levels in Table 1-1.

- The highest regional level population and built asset exposure occurs in populous regions: Auckland, Waikato, Wellington and Canterbury. Canterbury region has the most exposure for population, buildings, roads, electricity network components (transmission lines, structures and sites), potable water pipelines and both built and production land cover. The region's exposed population and built assets are mostly in Christchurch City.

- Production land is most exposed in key diary and pastoral production regions including: Waikato, Canterbury and Southland.

- Outside regions with the three main urban centres, railways in Manawatu-Whanganui region are the only built asset type with higher exposure at regional level. Natural or undeveloped land cover is most exposed on the West Coast, a region with high amenity value for tourism.

- Mean annual flood (MAF) discharge change in response to four regional climate change projection scenarios for 2036-2056 and 2086-2099 periods, was used as a proxy to approximate which flood exposed populations and assets were in catchments (Strahler 3) sensitive to climate change. At regional level, most exposed elements were in catchments within ±20% MAF change, with relatively small proportions located with catchments >20% MAF change in scenarios RCP2.6 2036-2056 and RCP 8.5 2086-2099.

- The national-scale flood exposure assessment methodology used in this study has several limitations that need to be recognised. Limitations largely arise from the availability of data, specifically flood hazard maps. The method has been designed to give an aggregate order-of-magnitude measure of exposure on a national basis and cannot be expected to be consistently accurate for every floodplain or location.

- The development of a national-scale flood hazard model suite is required for New Zealand to estimate and map the frequency and magnitude of present-day fluvial and pluvial flood inundation hazards and their response to future climate conditions.

Table 1-1: National and regional level exposure of elements at risk within identified New Zealand flood hazard areas.

Region*	Population (#)	Buildings		Transport			Electricity (National Grid)			Three-Waters		Land Cover (km^2)		
		Total (#)	Replacement Value (2016 NZD$ Billion)	Roads (km)	Railway (km)	Airports (#)	Transmission Lines (km)	Structures (#)	Sites (#)	Pipelines (km)	Nodes (#)	Built	Production	Natural or Undeveloped
Northland	15,237	14,263	3.4	1,141	163	0	51	53	0	515	15,619	9	896	141
Auckland	118,172	48,167	27.6	1,259	196	3	214	243	4	4,409	146,165	29	622	177
Waikato	89,012	60,008	15	2,542	176	1	583	1,262	8	1,614	25,228	58	2,288	391
Bay of Plenty	18,322	13,450	3.3	667	36	2	57	119	0	1,269	37,034	15	310	223
Gisborne	15,455	11,804	2.2	371	18	1	0	0	0	417	8,663	9	228	31
Hawkes Bay	17,788	13,942	3.5	681	86	1	270	116	3	796	22,489	10	531	117
Taranaki	2,145	2,195	0.4	74	7	0	43	14	1	114	1,683	4	97	23
Manawatu-Whanganui	26,975	25,206	5.2	1,213	234	3	388	1,006	4	571	9,503	12	1,544	232
Wellington	77,675	43,360	13.8	1,515	37	0	93	138	6	3,453	73,053	34	511	184
Tasman	20,740	11,072	2.9	789	0	0	38	2	0	620	19,063	10	424	118
Nelson	12,029	6,873	2.1	130	0	1	3	85	1	895	24,336	7	21	12
Marlborough	4,674	3,760	1.0	387	25	1	205	160	1	8**	126**	3	394	140
West Coast	9,136	5,901	1.5	1,025	212	2	247	180	5	281	7,885	6	1,038	1,207
Canterbury	189,012	116,713	40	3,947	156	2	808	672	10	4,177	No Data	112	2,991	949
Otago	41,447	21,684	8.7	1,386	136	1	126	1,355	2	1,782	47,482	23	1,111	410
Southland	17,672	13,118	4.2	1,971	95	2	268	443	4	250	4,170	15	2,180	979
NZ Total	**675,491**	**411,516**	**135**	**19,098**	**1,577**	**20**	**3,397**	**8,848**	**49**	**21,173**	**442,499**	**358**	**15,190**	**5,335**

*2016 regional council boundaries.

** Limited data.

1 Introduction

Flooding is New Zealand's most frequent damaging natural hazard (Rouse, 2012). Insurance claim statistics indicate damaging flood events have been increasing since the late 20th century (Smart and McKercher, 2010). Future climate change will cause sea levels to rise and could increase heavy rainfall events potentially increasing flood inundation hazard. When these are coupled with urban development in or near active floodplains they would expose New Zealand to more frequent damage and disruption from flood hazard events leading to higher economic losses.

The Deep South Science Challenge (DSC) mission is to enable New Zealanders to adapt, manage risk, and thrive in a changing climate. Within the Impacts and Implications Programme, the DSC commissioned a 2-year research project "*Emergent exposure of flood inundation hazards under future climate change in New Zealand*"[1] to estimate population, building, infrastructure and land cover exposure to present and future flood hazards.

This study is a first attempt to estimate New Zealand's exposure to fluvial and pluvial flooding. A national flood hazard area map was composed from publicly-available information and used to enumerate intersecting populations, buildings, infrastructure (transport, electricity three-waters) and land cover. Exposure of these elements is reported at national, regional, and territorial levels. In addition, flood-exposed elements located in catchments sensitive to changes in mean annual flood discharge are enumerated. The potential implications of this study for future flood hazard exposure and loss modelling under current and future climate scenarios are discussed.

2 Methods

The most significant constraint on a national-scale flood exposure assessment methodology is the availability of data. New Zealand does not have nationally consistent flood hazard maps to identify elements at risk in fluvial and pluvial floodplains. As an interim measure, this study composes a potential "flood hazard area map" (FLHA) for New Zealand using relevant, publicly-available flood hazard maps from local government organisations and flood-prone soil maps from Landcare Research. The details of this map are given in Section 2.1. Details of how we gather information on potentially vulnerable elements (reported at national, regional and territorial levels) are given in Section 2.2 and the methodology for enumerating those elements that lie within the FLHA is given in Section 2.2.5. The methodology for considering the effects of climate change on the flood inundation risk is given in Section 2.3

2.1 Flood Hazard Area Mapping

2.1.1 Modelled and historic flood hazard maps

Regional, unitary and territorial authorities are the primary holders of flood hazard maps in New Zealand. Public map access has recently improved with many organisations providing web map portals (e.g. ESRI ArcGIS and IntraMaps) for spatial information viewing and data extraction using geospatial information system RESTful (Representational State Transfer) services.

In August 2018 an online search found public flood hazard maps for thirteen[2] regional councils and unitary authorities. Fifteen territorial authorities also provide maps publicly. Online maps are mostly

[1] https://www.deepsouthchallenge.co.nz/projects/national-flood-risks-climate-change

[2] No maps available from West Coast Regional Council and Taranaki Regional Council.

made available with under Creative Commons Licence and accessible via GIS RESTful services. Waikato Regional Council provides static maps online and digital maps under data use agreement on request. A full list of GIS RESTful services providing flood hazard area maps and metadata is provided in a digital appendix (see. Appendix A) supplementary to this report.

Flood hazard maps publicly provided by local government organisations were created using a range of modelling or mapping methods. These include: numeric modelling (2-dimensions with LiDAR-based or similar topography or 1-dimensional with cross-sections), GIS mapping using LiDAR data and estimated or previous flood levels, historic flood event extents surveyed in the field and digitised flood inundation extents from post-event aerial photography. The resulting flood hazard maps have variable accuracy leading to some flood maps indicating “potential floodplain” areas rather than confirmed “flood hazard” areas identified from numeric modelling. Climate change influence on rainfall and sea level, two key parameters that determine the frequency and magnitude of flood inundation, was included in few flood hazard models and representative flood maps. Where climate change effects were included, a percentage increase in rainfall and fixed higher sea-level were generally used e.g. Maitai River, Nelson (Tonkin & Taylor, 2013).

Flood hazard area maps also represent a range of flood frequency scenarios for individual floodplains. Maps are commonly based on 0.5%, 1%, 2%, or 5% annual exceedance probability (AEP) flood scenarios (200, 100, 50, or 20-year annual recurrence intervals respectively). Scenarios rarely included residual flood hazards caused by infrastructure failure, except for some historic flood event maps e.g. Manawatu River (2004), Rangataikei River aka Edgecumbe Flood (2017). The flood hazard area map therefore, represents a range of design flood hazard scenarios across New Zealand with little consideration of residual risk.

A major caveat for this study is that publicly available modelled and historic flood maps in August 2018 did not provide national coverage for New Zealand floodplains (Figure 2-1 and Figure 2-2).

2.1.2 Flood prone soil maps

Flood hazard mapping undertaken by local government authorities often focuses on urban areas and settlements or land areas of strategic importance for infrastructure and development. This approach has limited rural land inclusion in fluvial and pluvial flood mapping for many locations across New Zealand (see Figure 2-1 and Figure 2-2).

Flood-prone soil maps were used in this study to identify potential FLHAs not covered by modelled or historic flood hazard maps. A ‘Flood Soil Layer (FSL) Flood Return Interval’ map[3] developed by Landcare Research (Webb and Wilson, 1995) categorises fluvial soils from the New Zealand Land Resource Inventory (NZLRI) and National Soils Database (NSD). Fluvial soil classes are classified into six rating groups, with five groups assigned an estimated flood frequency interval using a combination of flood frequency data from regional councils, flood scheme design levels and expert opinion. Areas representing flood-prone soils (Ratings 2 to 6 in Table 2-1) are mapped at 1:50,000 scale, providing New Zealand wide coverage. A visual overlay of FSL Flood Return Interval map with potential flood hazard area maps derived from numerical models and LiDAR topography, suggests that at a national level, the map provides a reasonable representation of potential flood hazard areas where modelled or historic flood hazard maps are not available (Figure 2-3 and Figure 2-4).

[3] https://lris.scinfo.org.nz/layer/48106-fsl-flood-return-interval/

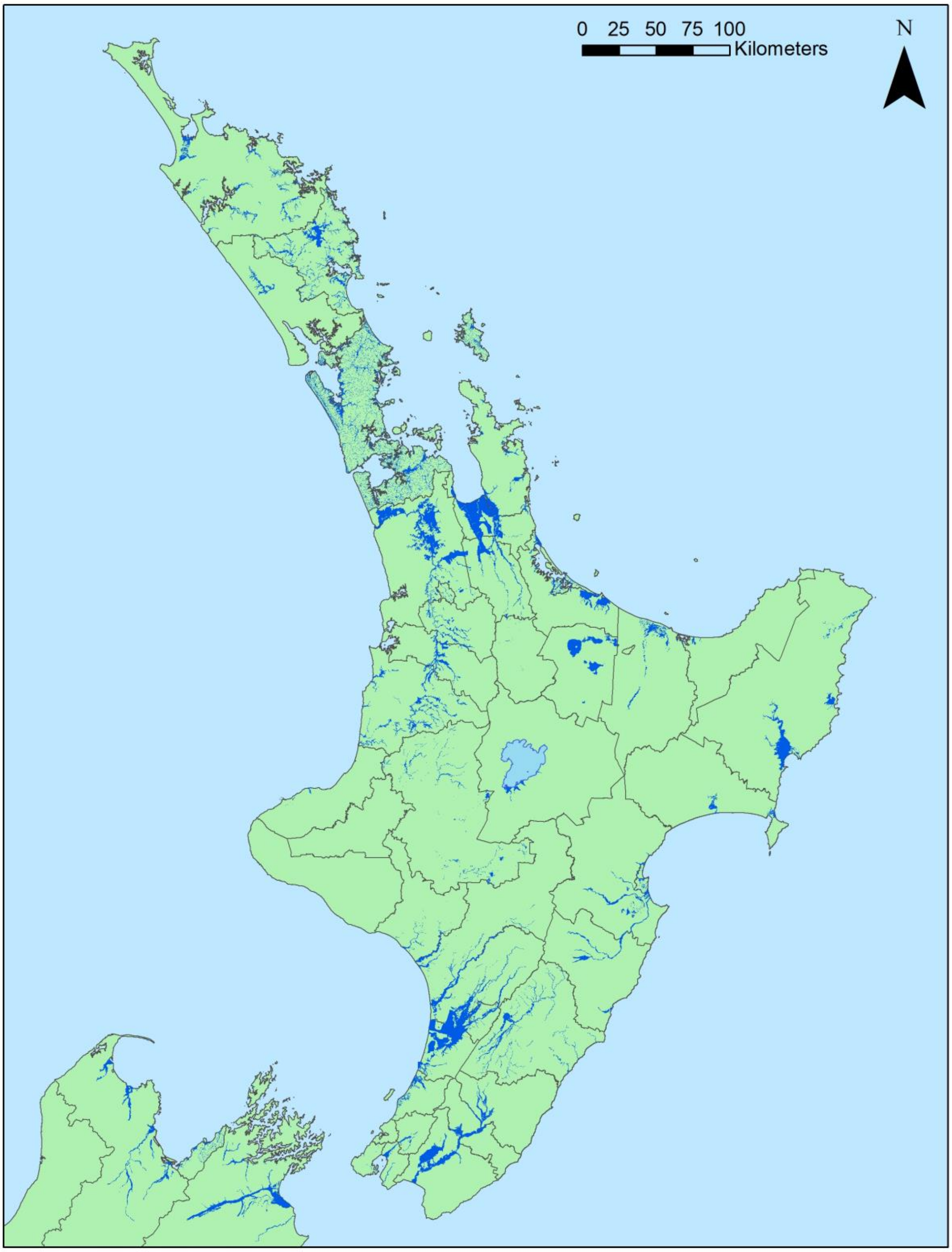


Figure 2-1: North Island modelled and historic flood hazard maps available from local government.

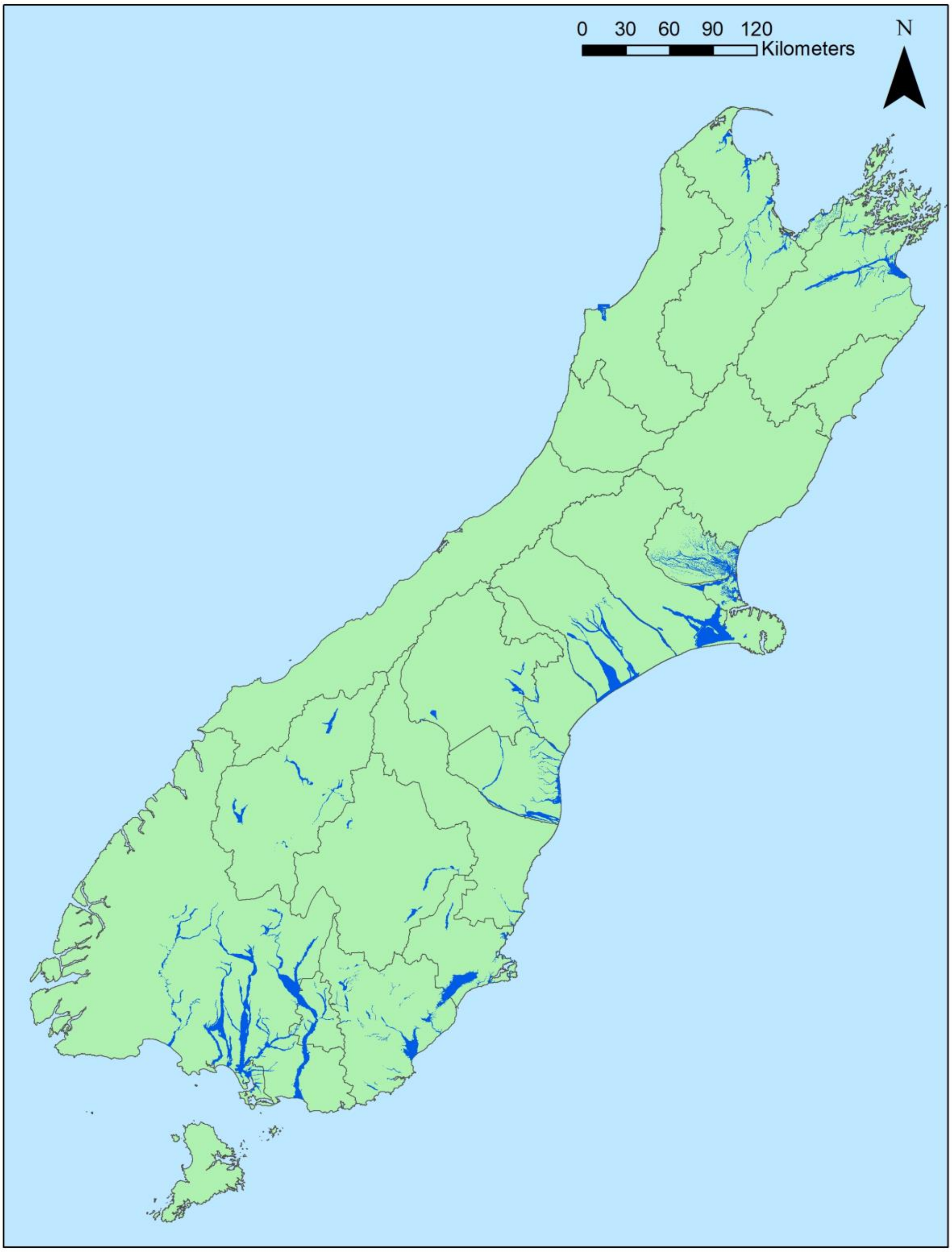


Figure 2-2: South Island modelled and historic flood hazard maps available from local government.

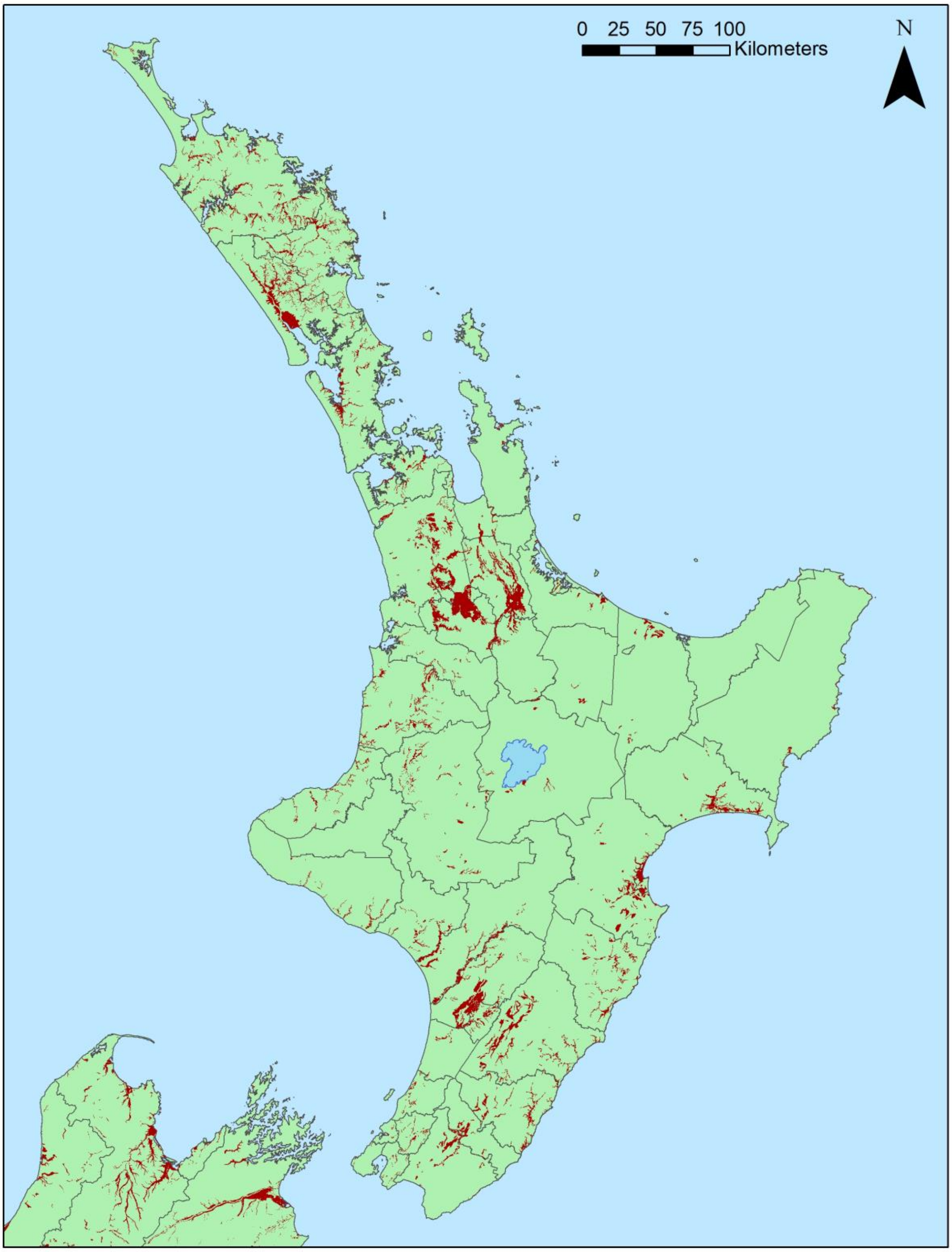


Figure 2-3: North Island Flood Soil Layer Flood Return Interval (Ratings 2 to 6) map.

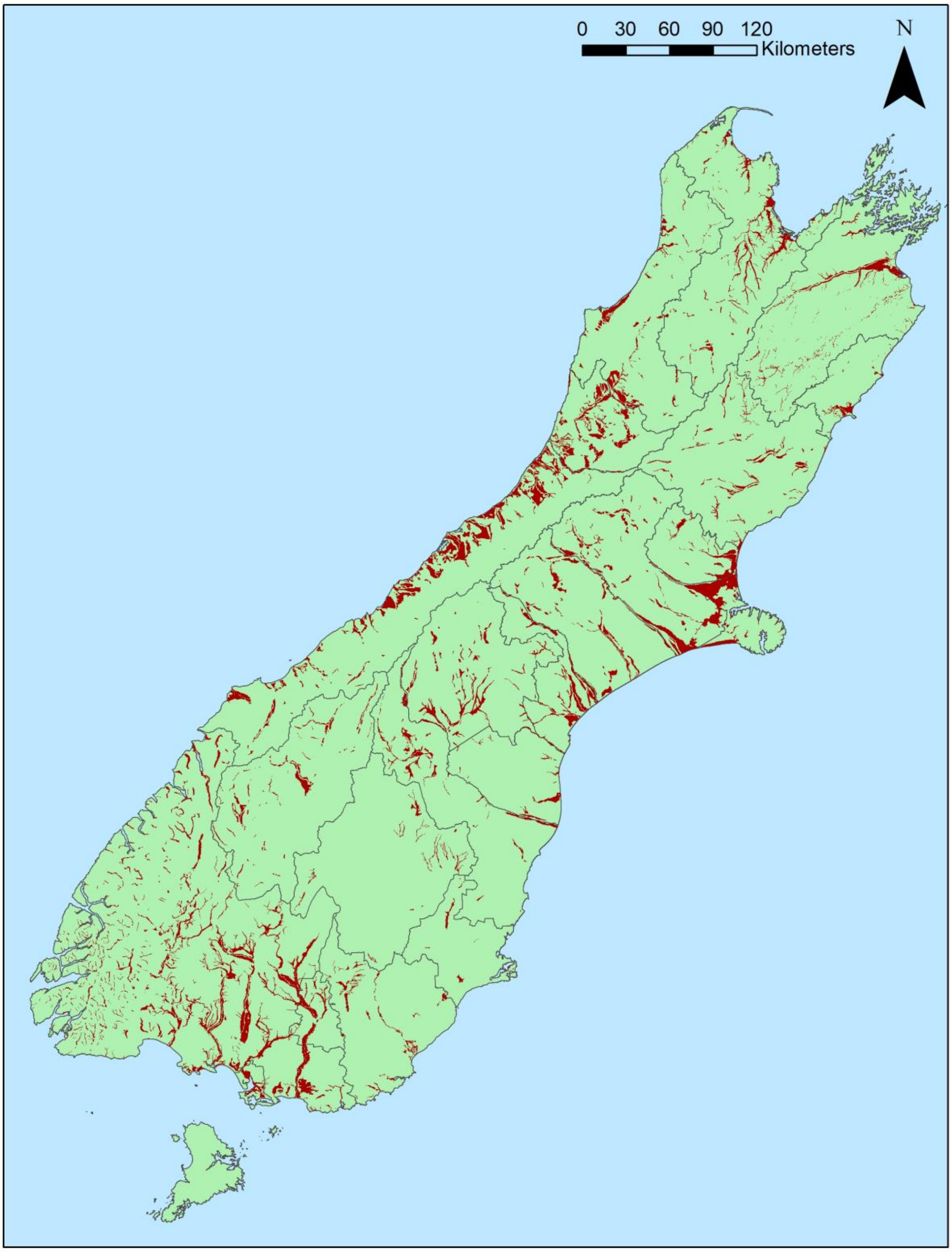


Figure 2-4: South Island Flood Soil Layer Flood Return Interval (Ratings 2 to 6) map.

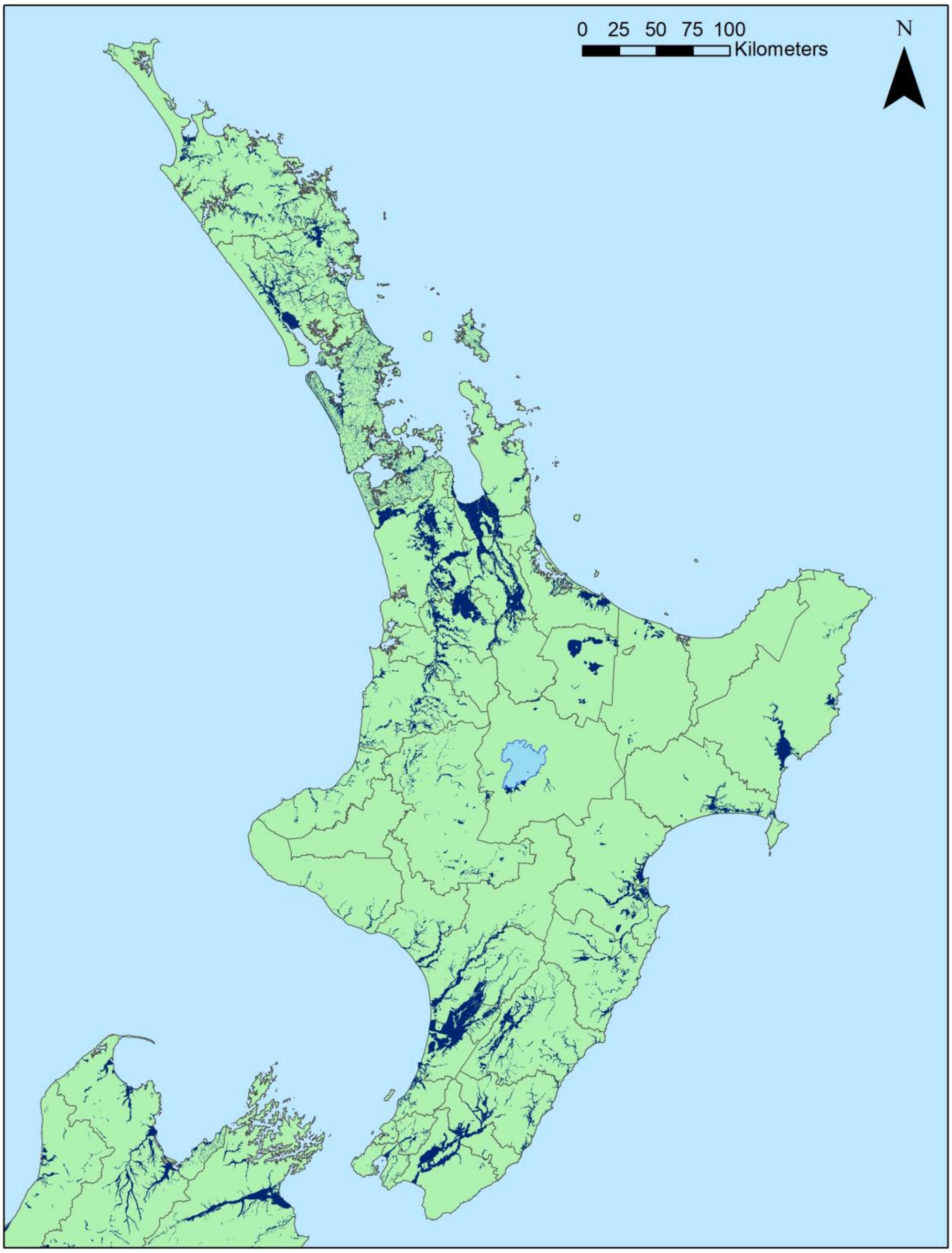


Figure 2-5: North Island Flood Hazard Area (FLHA) map.

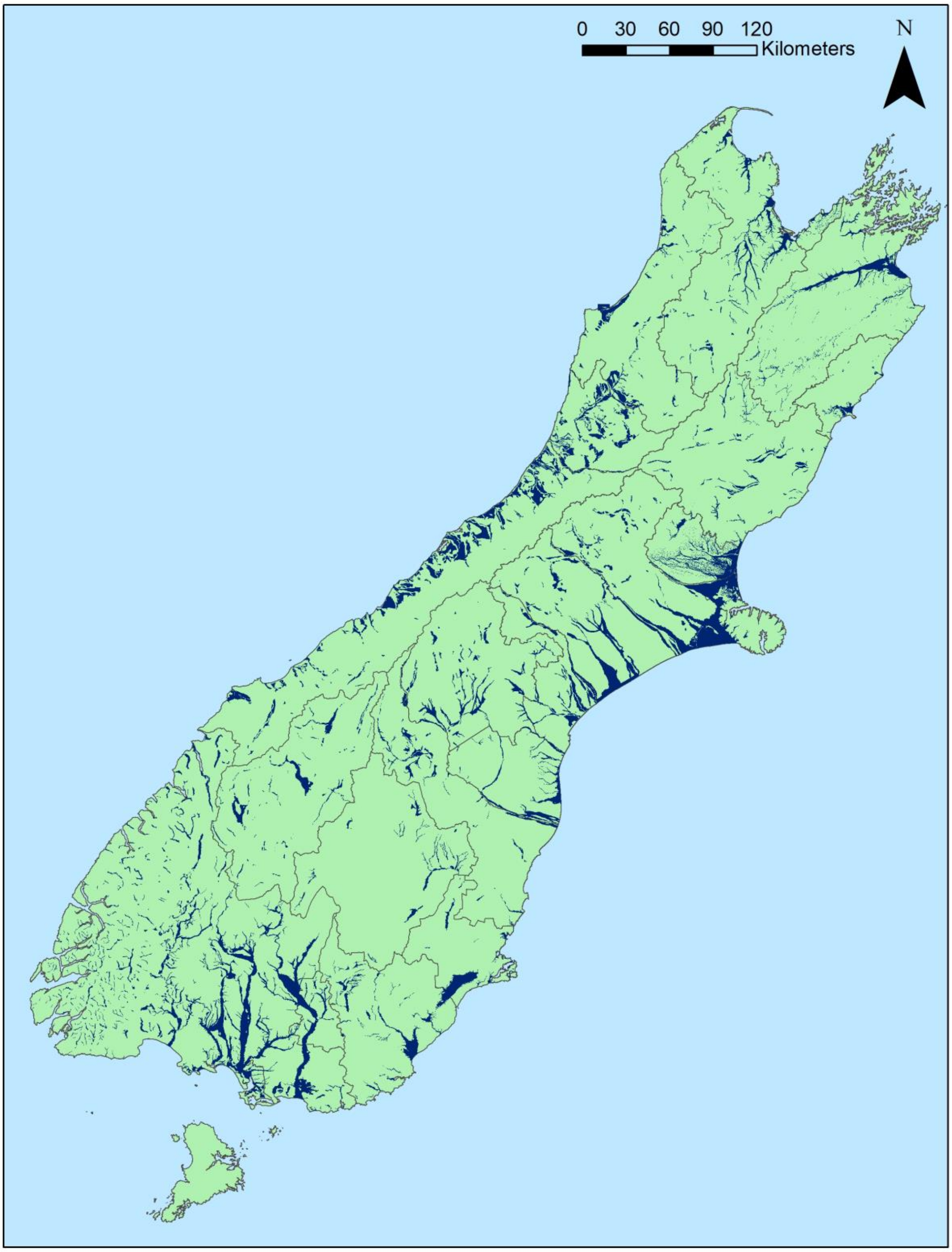


Figure 2-6: South Island Flood Hazard Area (FLHA) map.

Table 2-1: Classifications for 'Flood Soil Layer, Flood Return Interval' map (Webb and Wilson, 1995).

Flood annual return interval (years)	Class	Rating
Nil	Nil	1
>60	Slight	2
20-60	Moderate	3
10-20	Moderately severe	4
5-10	Severe	5
<5	Very severe	6

2.1.3 New Zealand flood hazard area map (FLHA)

In a first attempt to create a New Zealand flood hazard area (FLHA) map for national mapping of elements at risk in fluvial and pluvial floodplains, local government modelled and historic flood hazard maps were combined with the FSL Flood Return Interval map into a single spatial layer (Figure 2-5 and Figure 2-6). This 'composite' FLHA map represents known or potential flood-prone land. The map enables spatial mapping of elements at risk in floodplains for enumeration at national, regional and territorial levels. While better national-scale flood inundation hazard information should be a high priority, in its absence, this represents the best publicly available knowledge to date.

2.2 Elements at risk

New Zealand's elements at risk to fluvial and pluvial flood hazards in this study includes population, built assets (e.g. buildings, transport, electricity and three-waters infrastructure) and land cover. Specific elements this report considers are:

- Population (#)
- Buildings
  - Total number (#)
  - Replacement value (NZD 2016)
- Transport Infrastructure
  - Roads (km)
  - Railways (km)
  - Airports
    - Total number (#)
    - Area (km^2)
- Electricity Infrastructure
  - Transmission Lines (km)
  - Pylons (#)
  - Sites (#)

- Three-waters Infrastructure
  - Nodes (#)
  - Pipelines (km)
- Land Cover
  - Built Land (km^2)
  - Production Land (km^2)
  - Natural/Undeveloped Land (km^2)

This are not an exhaustive list of exposed elements in New Zealand's fluvial and pluvial floodplains. National-scale spatial datasets of each element used in this study are considered to provide the best available spatial information representing for New Zealand between August-October 2018. The underlying information for population, built assets (buildings and infrastructure) and land cover elements are described in sections 2.2.1 to 2.2.4 respectively.

2.2.1 Population

FLHA-exposed population was estimated from 2013 Census "usually-resident" meshblock data[4,5]. For this study, each residential building within the FLHA is assumed to house the 'mean building occupancy rate' for that meshblock. Age group data was summed to derive total meshblock populations. Residential buildings represented in a national building dataset developed by NIWA and GNS Science (Bell and King, 2009) were totalled for each meshblock, with a 'mean building occupancy rate' estimated for each residential building point features available in the dataset. Populated residential building features enabled the mapping and enumeration of populations in the FLHA.

Populations represented at residential building feature locations relies on accurate building and 2013 census datasets. In 2018, recently constructed residential buildings may not be available in the national building dataset and "usually-resident" meshblock populations will have changed since 2013 census night. Despite the temporal difference between 2013 census night and this 2018 study, assigning 2013 populations "usually-resident" to residential buildings was considered appropriate for estimating exposed populations at regional and territorial levels in the absence of high-resolution population data.

2.2.2 Buildings

New Zealand building spatial information is provided by a national dataset developed by NIWA and GNS Science (Bell and King, 2009). The dataset contains structural and non-structural attributes for over 2.4 million buildings, sourced primarily from QV Property Valuation datasets with additional building attributes included from field surveys (Cousins, 2009). 'Use category' and 'replacement value' attributes were identified for exposed building features. Reported use categories (Table 2-2) were summarised as; residential, commercial, industrial (includes primary production), critical facility, community and other (e.g. out-buildings, garages). Replacement values in NZD 2016 were derived using the method described by Cousins (2009). Values are estimated using New Zealand

[4] http://archive.stats.govt.nz/Census/2013-census/data-tables/meshblock-dataset.aspx
[5] 2018 Census "usually-resident" meshblock data was not available for population exposure mapping in August 2018.

2016 (3rd quarter) construction cost rates published by Quotable Value[6], assigned to buildings based on use category, construction type, floor area and storeys.

Table 2-2: Building use categories reported for this study.

RiskScape Building Use Categories	Reported Use Category
1: Residential Dwellings; 15: Resthome; 19: Lifestyle	Residential
2: Commercial – Business; 3: Commercial – Accommodation; 6: Fast Moving Consumer Goods Commercial	Commercial
4: Industrial - Manufacturing, Storage; 5: Industrial - Chemical, Energy, Hazardous; 17: Forestry, Mining; 18: Farm	Industrial
7: Government; 8: Territorial Authority/Civil Defence; 9: Lifeline Utilities; 10: Police; 11: Hospital, Clinic; 12: Fire Station; 14: Education	Critical Facility
13: Community; 16: Religious Community	Community
20: Parking; 21: Clear Site; 22: Other	Other

2.2.3 Infrastructure

National datasets for transport and electricity infrastructure assets were acquired from New Zealand Transport Agency (NZTA), Land Information New Zealand (LINZ) and Transpower online GIS data portals (see Appendix A). Transport and electricity infrastructure asset datasets are considered current at August 2018.

NZTA maintains a spatial dataset of road features represented as polyline features. LINZ provides spatial datasets of railway (i.e. tracks) polylines and airports (i.e. land parcels) polygons features. Road and railway feature lengths were calculated in GIS to enable enumeration of asset length in the FLHA.

Transpower maintains national grid electrical infrastructure asset data for transmission lines as polyline features, structures (i.e. pylons), and sites (e.g. substations, buildings, etc.) point features. Transmission feature lengths were calculated in GIS to enable enumeration of asset length in the FLHA.

Three-waters infrastructure asset datasets were extracted from territorial or unitary authority GIS RESTful services, or where not available online, available spatial data provide on request. These datasets included potable water, wastewater, and stormwater network node points and pipe polyline features. Node component types were aggregated into single feature layers for each three-waters network (Table 2-3). Node and pipe asset datasets were not available for all territorial and authorities. Three-waters infrastructure asset datasets available from online GIS RESTful services is provided a digital appendix for this report (see Appendix A).

[6] https://qvcostbuilder.co.nz/

Table 2-3: Three-waters infrastructure node component types reported in this study.

Three-waters Category	Node Components
Potable Water	Back Flow Prevention Device; Control Cabinet; Chamber; Connector; Filter; Fitting; Hydrant; Intake; Manhole; Meter; Pump Station; Reducer; Restrictor; Reservoir or Dam; Valve; Vent; Tank; Tap; Tee; Telemetry; Toby; Treatment Plant; Well
Wastewater	Access Point; Aeration pond; Aerator; Bio filter; Control cabinet; Chamber; Cleaning eye; Fitting; Flushing point; Generator; Inlet; Inlet structure; Inspection point; Intake; Manhole; Meter; Oxidation pond; Outlet; Outlet Structure; Pump; Pump Station; Reducer; Structure; Telemetry; Treatment Plant; Valve; Vent
Stormwater	Access Point; Chamber; Cleaning eye; Catchpit; Collection pond; Connector; Culvert; Detention dam; Floodgate; Inlet; Inlet structure; Intake; Manhole; Natural structure; Outfall; Outlet; Outlet Structure; Pump; Pump Station; Reducer; Septic Tank; Soak pit; Tank; Telemetry; Valve; Water Treatment; Device; Well; Water Treatment Facility

2.2.4 Land Cover

New Zealand Land Cover Database Version 4.1 (LCDBv4.1)[7] developed by Landcare Research is a polygon dataset representing thirty-three land cover classes. Land cover areas were spatially mapped from satellite imagery acquired during a 2012 to 2013 period. Land cover classes were aggregated for this study into three broad types: built, production, and natural or undeveloped (Table 2-4). Land cover polygon feature areas were calculated in GIS to enable enumeration of asset areas in the FLHA.

Table 2-4: Land Cover Database Version 4.1 classes and land cover types reported in this study.

Land Cover Database Version 4.1 Categories	Reported Land Cover Category
3: Built-up area; 33: Transport infrastructure Built-Environment	Built
7: Exotic forest; 10: Forest – harvested; 15: High producing exotic grassland; 20: Low producing exotic grassland; 25: Orchard vineyard and other perennial crops; 29: Short-rotation crop; 31: Surface mines and dumps	Production
1: Alpine grassland/herbfield; 2: Broadleaved indigenous hardwoods; 4: Deciduous hardwoods; 5: Depleted grassland; 6: Estuarine open water; 7: Exotic forest; 8: Fernland; 9: Flaxland; 11: Gorse and/or broom; 12: Gravel and rock; 13: Herbaceous freshwater vegetation; 14: Herbaceous saline vegetation; 16: Indigenous forest; 17: Lake or pond; 18: Land Cover; 19: Landslide; 21: Mangrove; 22: Manuka and/or Kanuka; 23: Matagouri or grey scrub; 24: Mixed exotic shrubland; 26: Permanent snow and ice; 27: River; 28: Sand and gravel; 30: Sub alpine shrubland; 32: Tall tussock grassland;	Natural or undeveloped

2.2.5 Exposure mapping of elements at risk

The methodology to enumerate elements in the FLHA applied the following tasks in ArcGIS 10.4.1:

1. clip spatial layers representing population, built assets and land cover features[8] in the FLHA layer;
2. intersect clipped feature layers with 2016 regional council and territorial authority geographic boundary layers;

[7] https://lris.scinfo.org.nz/layer/48423-lcdb-v41-land-cover-database-version-41-mainland-new-zealand/
[8] http://desktop.arcgis.com/en/arcmap/10.3/tools/analysis-toolbox/clip.htm

3. calculate geometries (i.e. length and area) for features represented as polylines (e.g. roads, railways, pipelines) and polygons (e.g. airports, land cover); and
4. spatially join feature layers with 2016 regional council and territorial authority geographic boundary layers to calculate exposure metrics (i.e. count (#), length and area).

2.3 Linking flood hazard exposure with climate change

NIWA has previously assessed potential climate change effects on agricultural water resources and flood flows in New Zealand (Collins and Zammit, 2016). The assessment applied NIWA's national hydrological model and six downscaled Global Climate Models (GCM) for 1971 and 2099 to assess the percentage change in mean annual flood (MAF) discharge under four radiative forcing scenarios or Representative Concentration Pathways (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) over 2036 to 2056 and 2086 to 2099 periods. The analysis was performed for 43,862 Strahler 3 catchments. The proportion of MAF discharge change was binned into 20% bands from a proportionate increase in MAF of over 100% to a decrease of between 80 and 100% (Figure 2-7). Many catchments could experience MAF discharge increases, particularly for the RCP8.5 scenario between 2086-2099).

There is considerable uncertainty over the effects of climate change on flood inundation. Sea level rise will increase the hazard in coastal areas and increases in the amount or intensity of rainfall could also increase flood hazard. This study uses MAF change as a proxy for estimating potential asset and population flood hazard exposure change under future climate change. This study analysed the corresponding MAF change for flood exposed assets and populations identified in the FLHA (Section 3.8) for each of the four RCP scenarios and two timeframes 2036 to 2056 and 2086 to 2099).

2.4 Methodological limitations

The national-scale flood exposure assessment methodology used in this study has several limitations that need to be recognised. Limitations largely arise from the availability of data, specifically flood hazard maps. The method has been designed to give an order-of-magnitude aggregate measure of exposure on a national basis and cannot be expected to be consistently accurate for every floodplain or location. Key limitations for datasets used in this study should be noted are as follows:

- Flood Hazard Area Map (FLHA):
  - Flood hazard area maps are not developed and available for all New Zealand floodplains.
  - Only publicly available maps were used that indicate potential flood hazard areas. Other maps that provide more detail on the hydrodynamic characteristics of flood hazards could be available.
  - Modelled flood hazard maps represent a range of scenario-based flood magnitudes and frequencies. Inter- and intra- regional variations of these flood hazard characteristics are readily observed for modelled flood hazard maps.
  - High resolution topographic data (i.e. LiDAR) may not have been used to model or map flood inundation in some floodplains.
  - Modelled flood hazard maps:

    - Were produced using a range of different hydrodynamic flood inundation modelling software and methods. Flood hazard maps developed using high resolution modelling methods provide a more accurate representation of flood hazard areas.
    - Include input parameters (e.g. rainfall, surface roughness) for modelled flood map scenarios are representative for the time of model development.
    - May exclude physical features (e.g. stopbanks, culverts, bridges) that influence flood hazard characteristics in modelled flood scenarios.
    - Residual flood hazards (e.g. stopbank failures) were often excluded in modelled flood scenarios.
    - Rarely consider the influence of climate change (e.g. rainfall and sea level rise), or land use change on flood hazard characteristics in modelled flood scenarios.
  - Historic flood maps are often digitised from expert interpretation aerial photography and may not consider local topography. Local flood hazard characteristics may have change since historic flood events due to many factors (e.g. flood protection structures, channel maintenance, land use change) that could alter flood inundation magnitude.
  - Flood prone soil maps are not defined from hydrodynamic flood inundation modelling and may not consider local topography.
- Elements at Risk (i.e. population, built assets, land cover):
  - "Usually-resident" population is representative of the 2013 census.
  - Building replacement values are derived for NZD$ 2016 and based on broad building categories.
  - The building dataset provides national coverage though floodplain buildings may be absent for specific sites in 2018.
  - Land cover areas are representative for a 2012 to 2013 period.
  - Transport and electricity infrastructure features are representative for August 2018.
  - Three-waters infrastructure are representative for August 2018 and were not available for all territorial authorities. Notably, three-water node features were not publicly available for Christchurch City for this study.
  - Not all exposed elements in floodplains are considered.
  - Only replacement values for building structures is reported. These values do not represent direct or indirect economic loss from flood damage (e.g. building repair costs, contents repair costs, clean-up costs, business disruption, etc.).

- Climate change effects:
  - No flood hazard maps were used to assess the potential future effects of climate change.
  - Mean annual flood (MAF) discharge change represented at Strahler 3 catchment level is used as a proxy to infer potential flood exposed asset sensitivity to flood hazard change in response to future climate conditions.
  - MAF discharge is not representative of other flood scenarios e.g. 1% AEP or 1 in 100-year ARI flood event. Elements identified in the FLHA may not be exposed to flood inundation in a MAF event. Lower frequency but higher magnitude flood hazard scenarios than the MAF (e.g. 1% AEP or 1 in 100-year ARI), are more likely to expose elements identified in the FLHA. The way these events are affected by climate change could be very different to the effect on MAF.

Despite these limitations, this study represents the most comprehensive assessment to date of the national floor exposure in New Zealand. Its limitations highlight the pressing need for more work in this area.

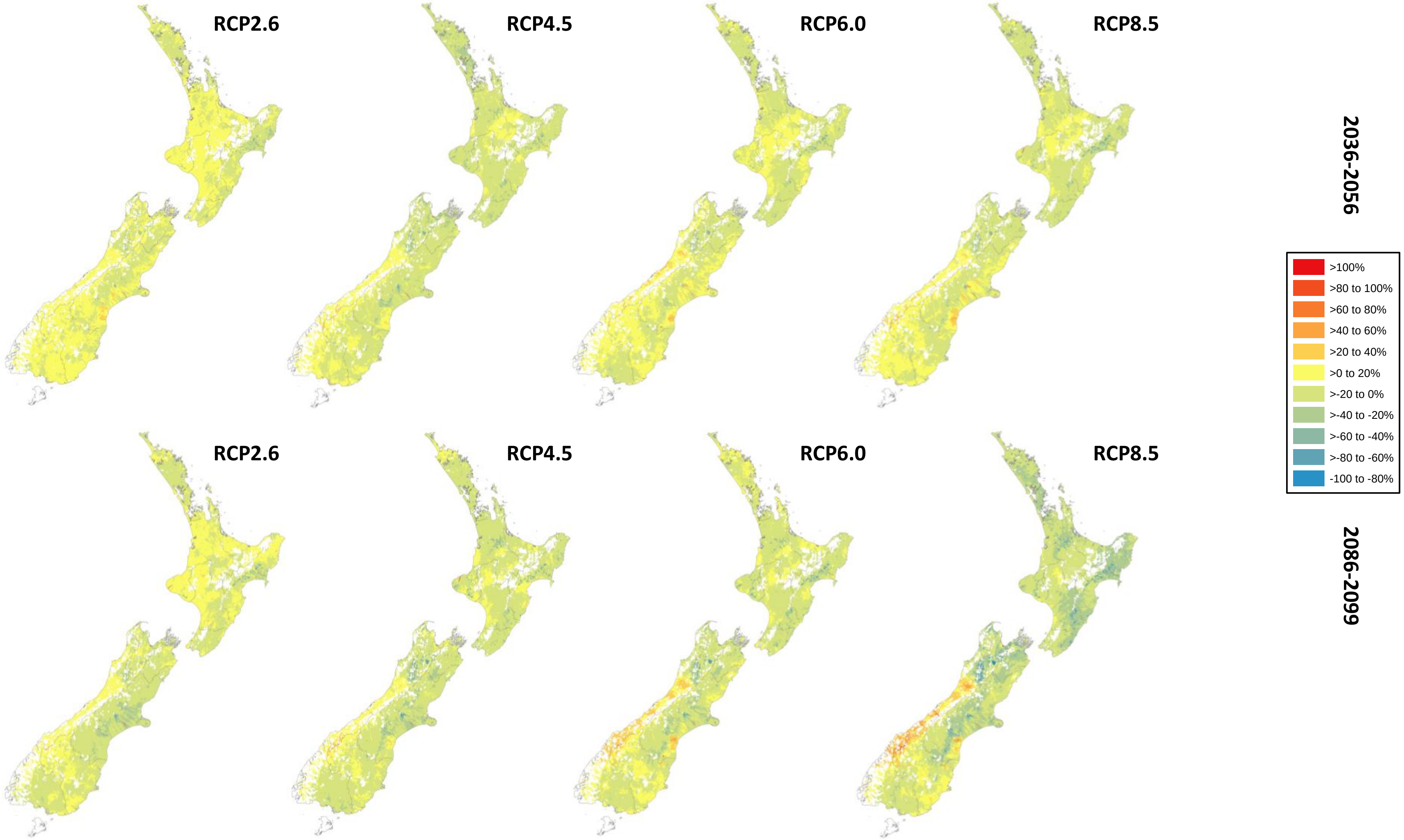


Figure 2-7: Median percentage changes in mean annual flood flow (Collins and Zammit, 2016).

3 Results

This section reports estimated population, built asset and land cover exposure from the national flood hazard area map (FLHA). Tabulated region and territory level exposure estimates are provided in a digital appendix (see. Appendix A) supplementary to this report.

3.1 Results Summary

Key observations from estimated population, built asset and land cover FLHA exposure reported in Sections 3.2 to 3.7 include:

- New Zealand's 2013 usually-resident population residing in the FLHA is approximately 675,500 people, with the highest populations residing Canterbury (~189,000) and Auckland (~118,000) regions.
- Over 400,000 buildings with an estimated 2016 replacement value of NZD$135 B are in the FLHA. This includes nearly NZD$100 B worth of residential buildings.
- The Canterbury region has nearly 110,000 residential buildings within the FLHA with an estimated 2016 replacement value of NZD$34 B.
- FLHA road exposure is almost 19,000 km with over 3,900 km located in Canterbury and 2,700 km in Waikato regions.
- More than 1,500 km of railway crosses the FLHA, mostly in Manawatu-Whanganui (233 km) and West Coast (212 km).
- 20 airports with more than 20 km^2 land lie within the FLHA, including Auckland and Christchurch international airports.
- New Zealand's national grid has 3,397 km of transmission lines crossing the FLHA, supported by 5,848 structures and 49 sites on flood prone land.
- Three-waters pipelines and nodes in the FLHA total 21,173 km and 442,499 nodes respectively. Potable water components are most exposed with 8,542 km of pipelines and 190,494 nodes. Regions with the most populous urban centre (Auckland, Wellington and Canterbury), have the highest pipeline exposure for each of the three-waters[9].
- The FHLA covers a 20,000 km^2 land area. FLHA production land covers 15,190 km^2 and is most highly exposed in key diary and pastoral production regions Canterbury (2,291 km^2), Waikato (2,288 km^2) and Southland (2,180 km^2).

3.2 Population

3.2.1 National

New Zealand's 2013 usually-resident population residing in the FLHA is approximately 675,000.

[9] Node data was not available in this study for Canterbury region.

3.2.2 Regions and territories

New Zealand most populous regions including Canterbury (~188,000) and Auckland (~118,000) have the highest 2013 usually-resident population exposure in the FLHA (Figure 3-1). In Waikato and Wellington region, more than 50,000 people are exposed. For these regions, high-resolution flood maps were often available to represent the FLHA for urban areas. The lowest population exposure is observed in West Coast, Marlborough and Taranaki regions, each with less than 10,000 people exposed.

Territories with large population centres have the highest FLHA population exposure. This includes Christchurch City (~148,000), Auckland (~118,000), Dunedin City (~35,000), Lower Hutt City (~31,000), and Hamilton City (~31,000).

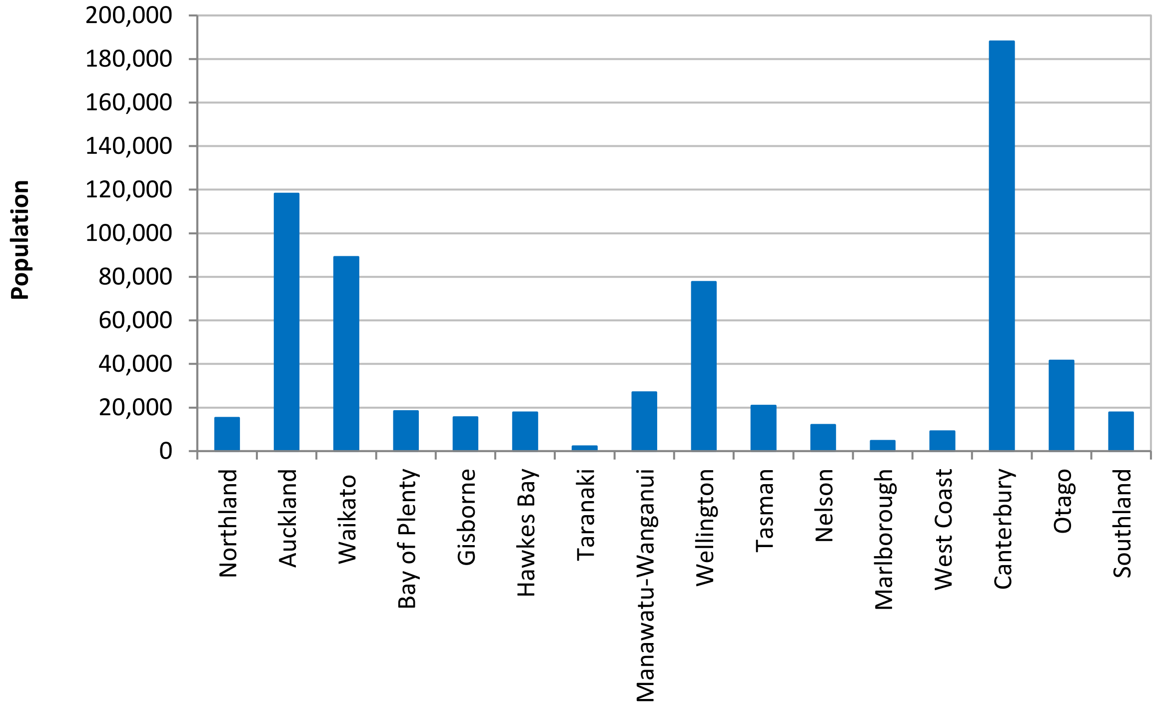


Figure 3-1: Region level 2013 usually-resident population exposure identified in the FLHA.

3.3 Buildings

3.3.1 National

FLHA building exposure is approximately 411,516 with a 2016 replacement value of NZD$134 B (Table 3-1). FLHA residential buildings exceed 70% of the total building and replacement value exposure.

3.3.2 Regions and territories

Residential buildings

Canterbury region has nearly 110,000 FLHA residential buildings with an estimated NZD$34 B replacement value (Figure 3-2a, b). Auckland has the next highest region with 40,879 buildings

(NZD$16 B) followed by Wellington with 37,212. Waikato's 35,735 FLHA residential buildings have a replacement value of NZD$11.8 B, over NZD$3.5 B more than Wellington.

The four territories with highest FLHA residential building and replacement value exposure, Christchurch City, Lower Hutt City, Hamilton City, and Waimakariri Districts are in three of the four most highly exposed regions (e.g. Canterbury, Wellington and Waikato).

Table 3-1: New Zealand building and replacement value exposure identified in the FLHA.

Building Use	Buildings (#)	Replacement Value (Millions of NZD 2016)
Residential	309,863	95,048
Commercial	7,676	10,578
Industrial	44,482	17,917
Critical Facilities	2,842	6,614
Community	2,429	2,925
Other	44,224	1,914
NZ Total	**411,516**	**134,997**

Commercial buildings

FLHA commercial building exposure is highest in three of New Zealand's four most populous regions. Auckland has the highest exposure with 1,166 buildings with a replacement value of almost NZD$3 B (Figure 3-3a, b). Otago has the second highest FLHA exposure and fourth highest replacement value. At territory level, the highest FLHA building and replacement value exposure occurs in Dunedin City, Christchurch City, Lower Hutt City and Wellington City.

Industrial buildings

Industrial (including primary production) buildings are most highly exposed in the FLHA for regions with large areas of dairy and pastoral production land. These include Waikato (6,521), Canterbury (5,436), Manawatu-Wanganui (4,802), Southland (4,423) and Otago (3,688) (Figure 3-4a). Auckland has the highest total replacement value exposure with NZD$5.2 B (Figure 3-4b). Christchurch City and Dunedin City respectively have NZD$2 B and NZD$1.4 B replacement value exposure.

Critical facilities

Higher numbers of critical facilities buildings occur in the FLHA for Auckland (766), Wellington (501) and Canterbury (337). Replacement values for buildings in these regions range between NZD$0.22 B and NZD$2.3 B (Figure 3-5b). Six territories exceed 100 critical facilities in the FLHA including: Christchurch City, Lower Hutt City, Dunedin City, Gisborne District, Tasman District and Waimakariri District.

Community buildings

Community buildings in the FLHA are most frequently exposed in populous regions such as Auckland (489) and Canterbury (301) (Figure 3-6a). Replacement value for exposed community buildings in Auckland, totals over NZD$400 M (Figure 3-6b). More than 100 FLHA community buildings are exposed in two territories, Christchurch City and Dunedin City, with replacement values exceeding NZD$100 M. Community buildings are often used as welfare centres during and after flood events, and their damage can severely disrupt emergency response and recovery activities, so the overall impact of their exposure could be greater.

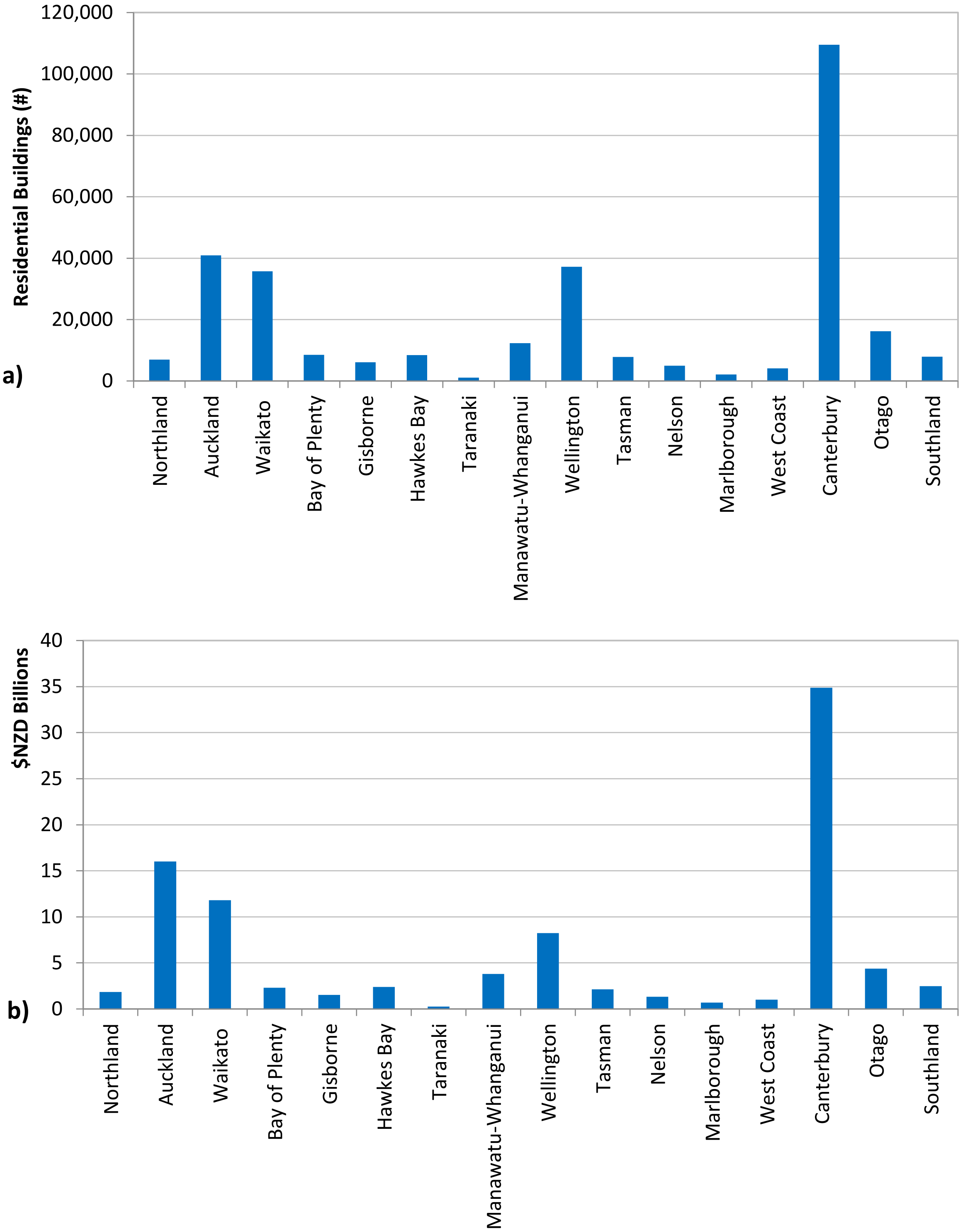


Figure 3-2: Region level residential building (a) and replacement value ($NZD 2016) (b) exposure in the FLHA.

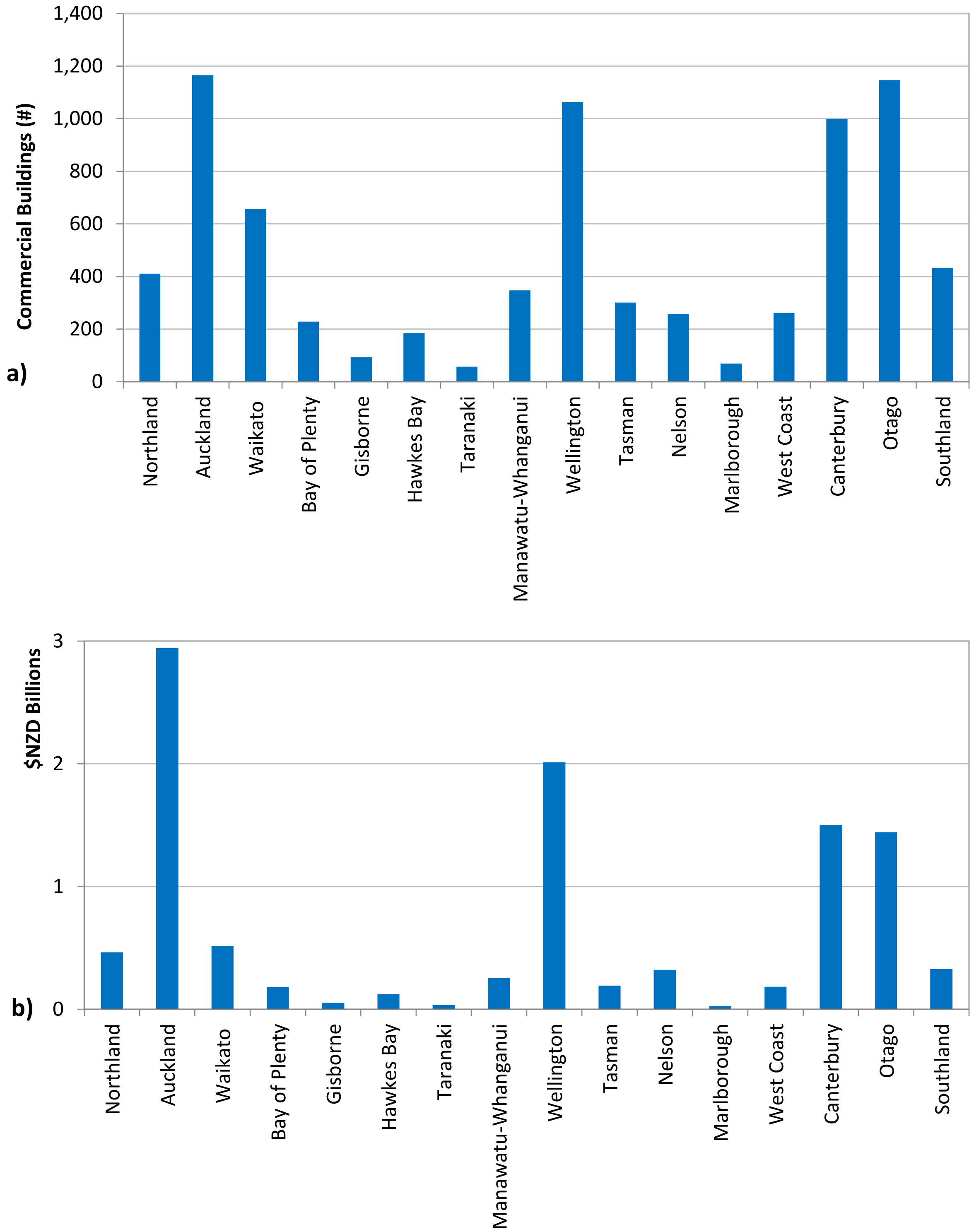


Figure 3-3: Region level commercial building (a) and replacement value ($NZD 2016) (b) exposure in the FLHA.

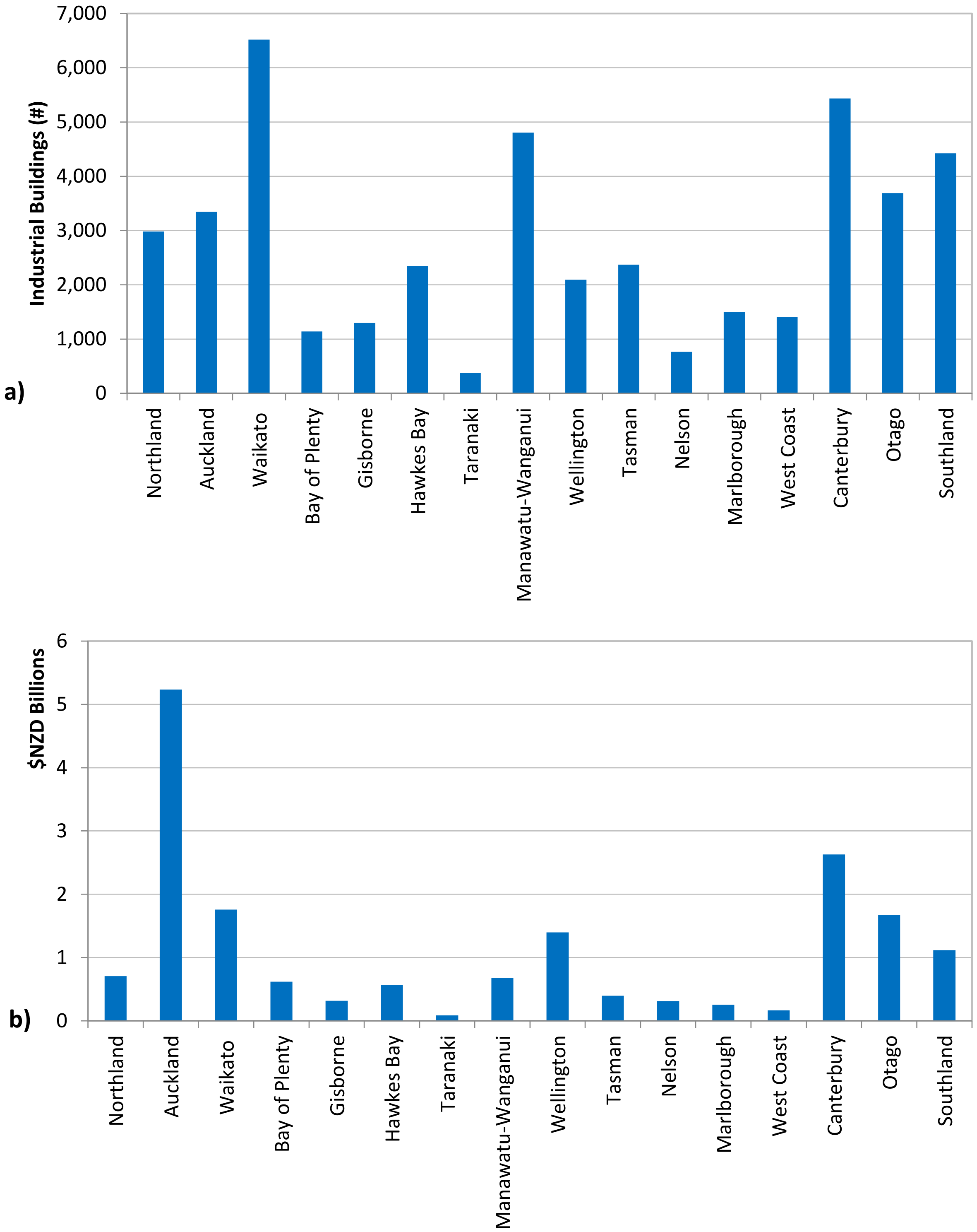


Figure 3-4: Region level industrial building (a) and replacement value ($NZD 2016) (b) exposure in the FLHA.

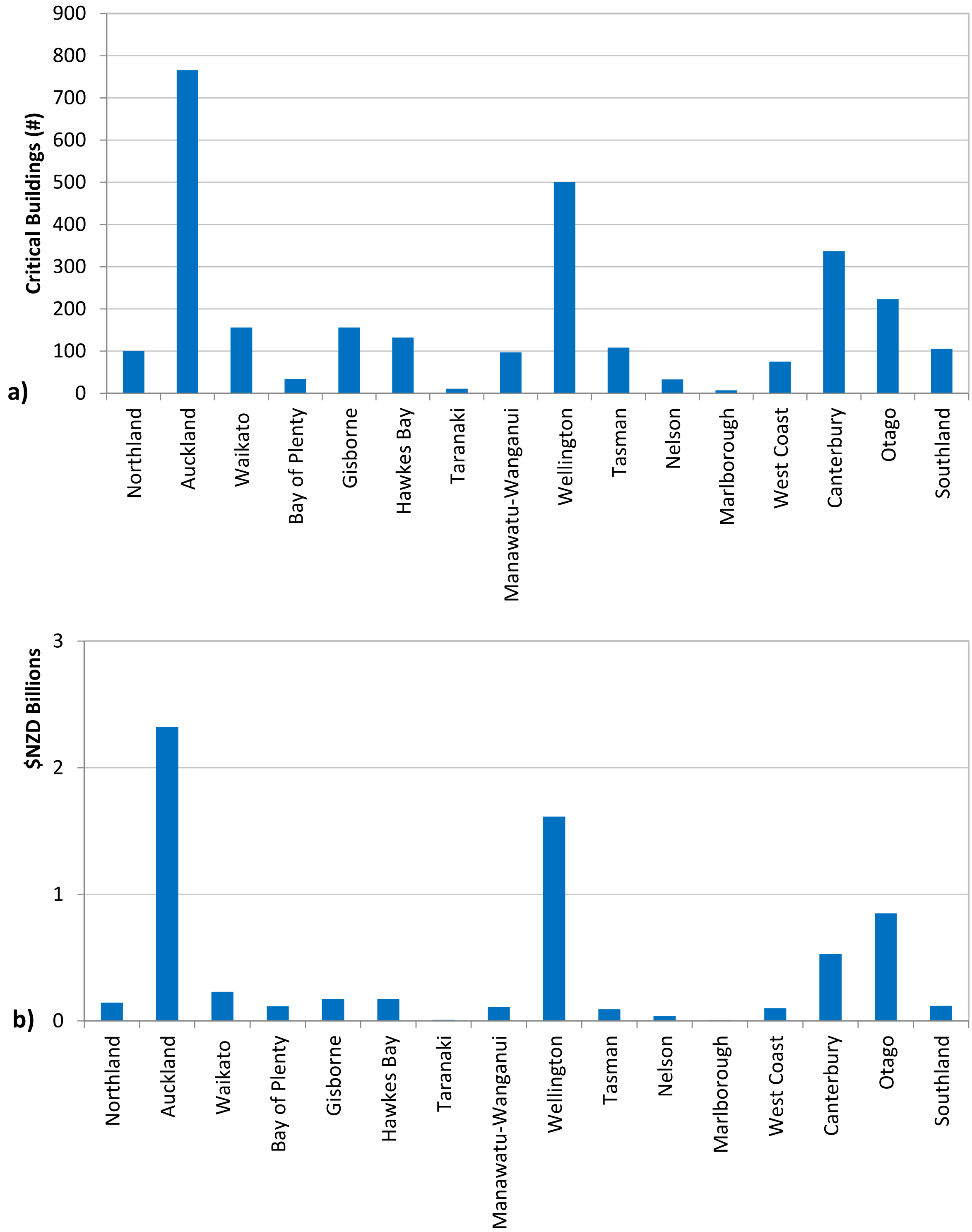
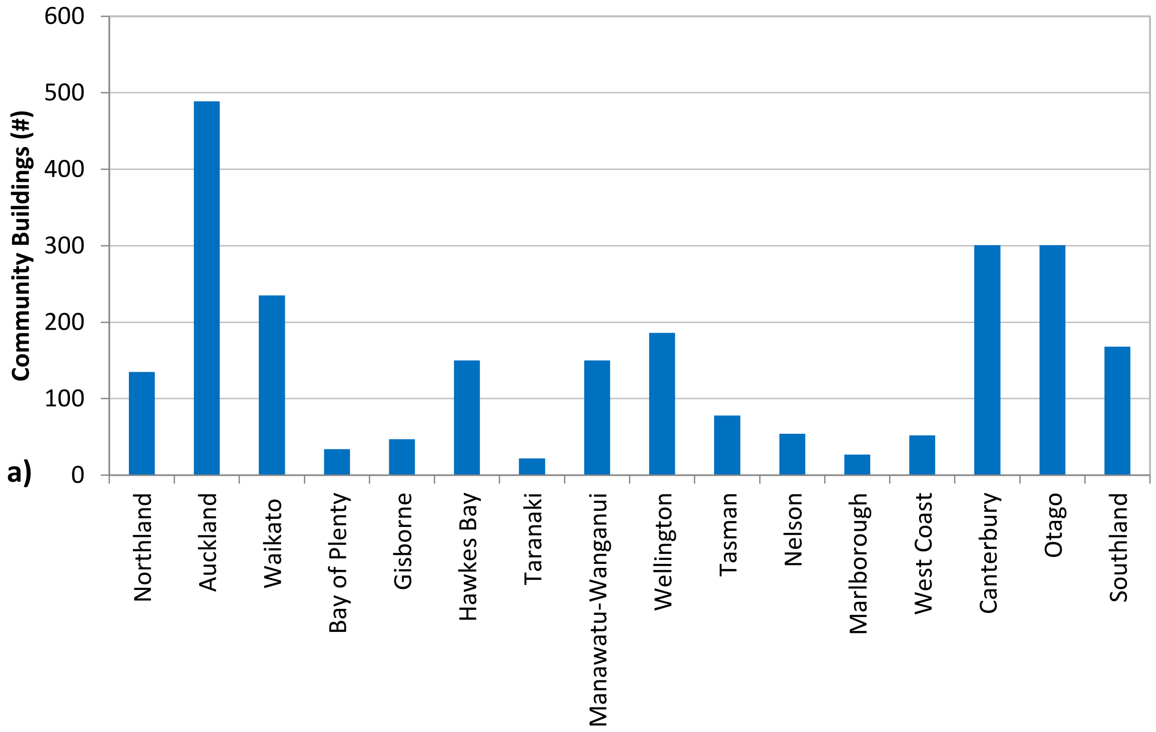


Figure 3-5: Region level critical building (a) and replacement value ($NZD 2016) (b) exposure in the FLHA.



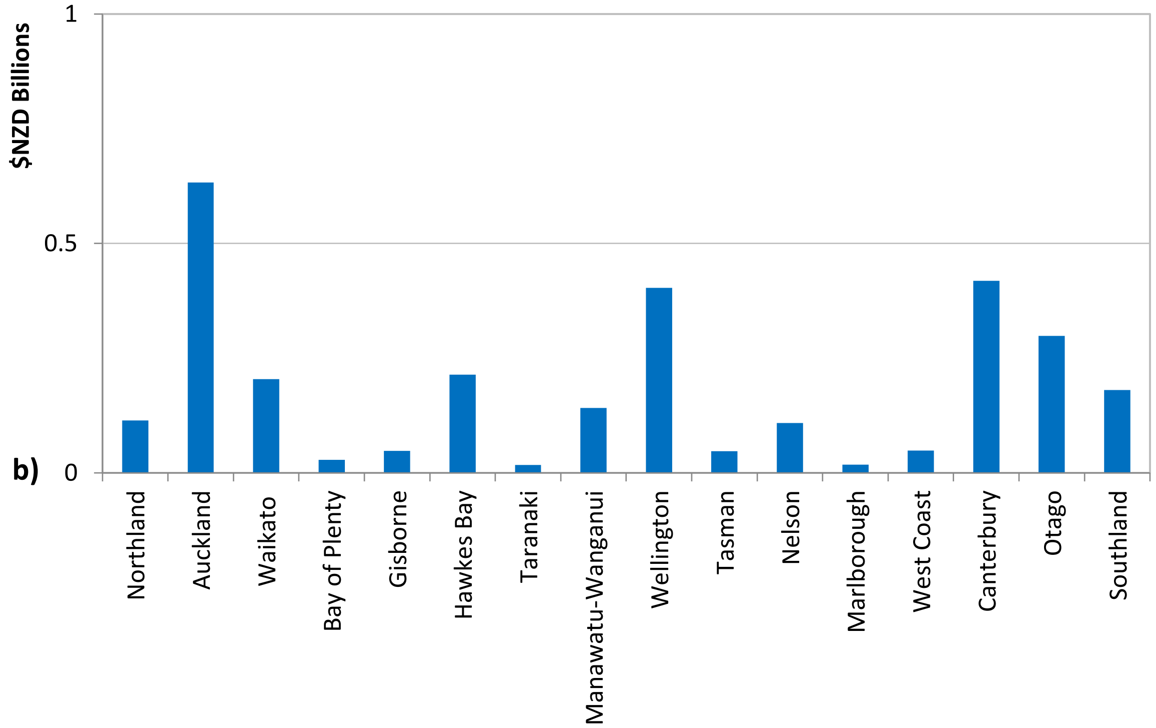
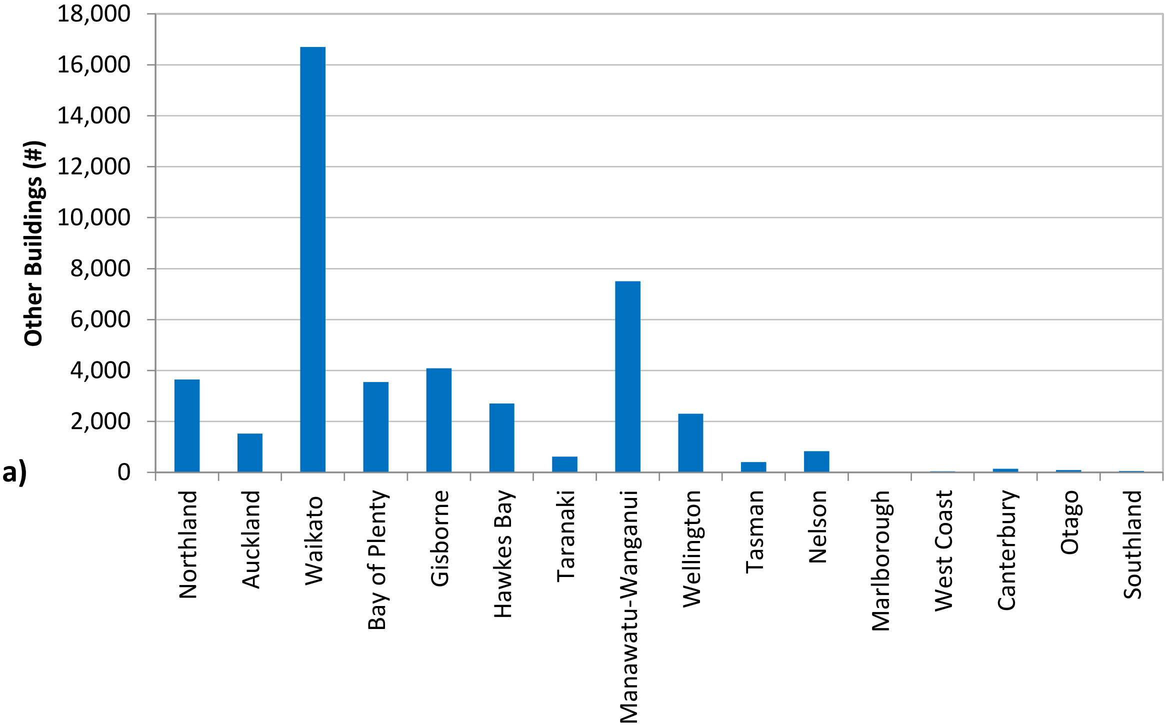


Figure 3-6: Region level community building (a) and replacement value ($NZD 2016) (b) exposure in the FLHA.

Other buildings

Buildings categorised as 'other' covers a wide range of uses not identified in the national dataset. Waikato (16,703) has almost one third of these buildings, with replacement values exceeding NZD$0.5 B (Figure 3-7a, b). Auckland has fewer buildings (1,523) but with a similar replacement value, suggesting a number of these are high value buildings.

a)



b)

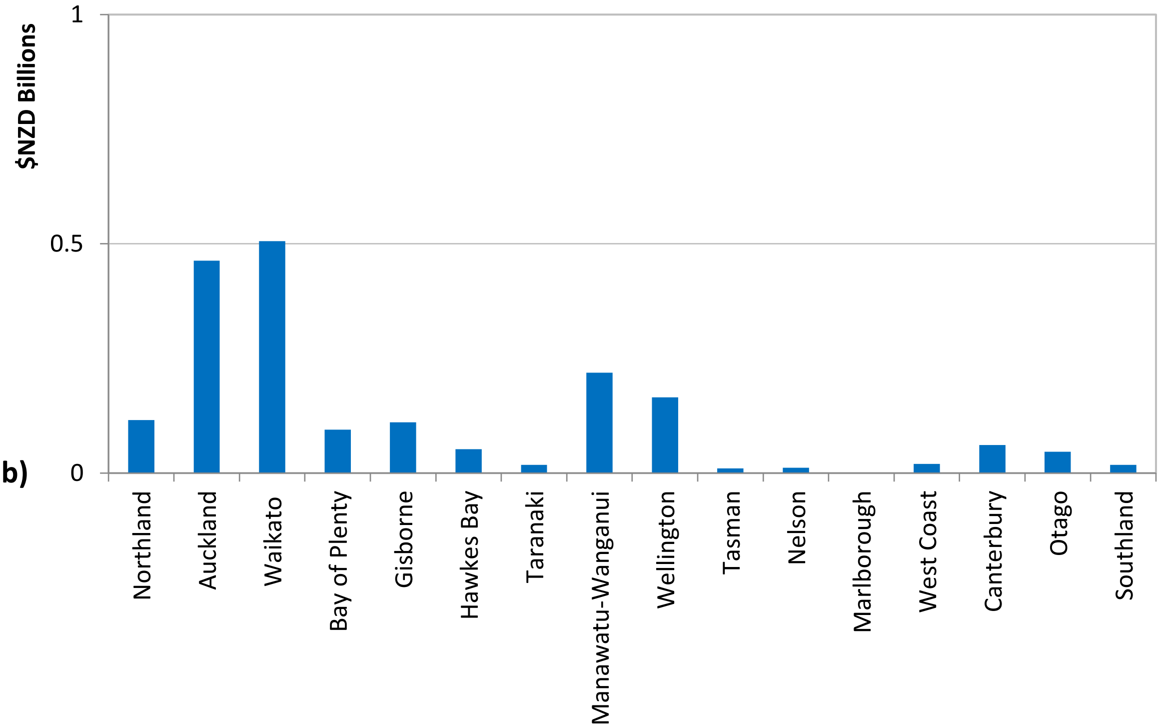


Figure 3-7: Region level 'other' building (a) and replacement value ($NZD 2016) (b) exposure in the FLHA.

3.4 Transport infrastructure

3.4.1 National

Just over 19,000 km of roads lie within the FLHA, approximately 20% of New Zealand's 96,722 km national road network. In addition, 1,577 km of tracks in the national railway network and 20 airports with more than 20 km^2 land are in the FLHA.

3.4.2 Regions and territories

Road network exposure in the FLHA exceeds 1,000 km in five regions (Figure 3-8). Canterbury region has the highest exposure in the FLHA, with over 3,900 km. Three territories also exceed 1,000km of road network exposure: Southland District (1,529 km), Auckland (1,259 km) and Christchurch City (1,232 km). Nelson has the highest proportion of regional and territory road network exposure, with approximately 39% (~130 km).

Railway network exposure in the FLHA exceeds 200 km in Manawatu-Wanganui and West Coast regions, and 150 km in Auckland, Waikato, Northland and Canterbury (Figure 3-9). Less than 40 km is exposed in Wellington region, although this includes sections of the high-use commuter network.

Multiple airports in Auckland (3) and Manawatu-Wanganui (3) are identified within flood hazard areas (Figure 3-10). Domestic and/or international airports in Auckland, Waikato, Manawatu-Whanganui, Hawkes Bay, Nelson, Canterbury and Dunedin are identified in the FLHA.

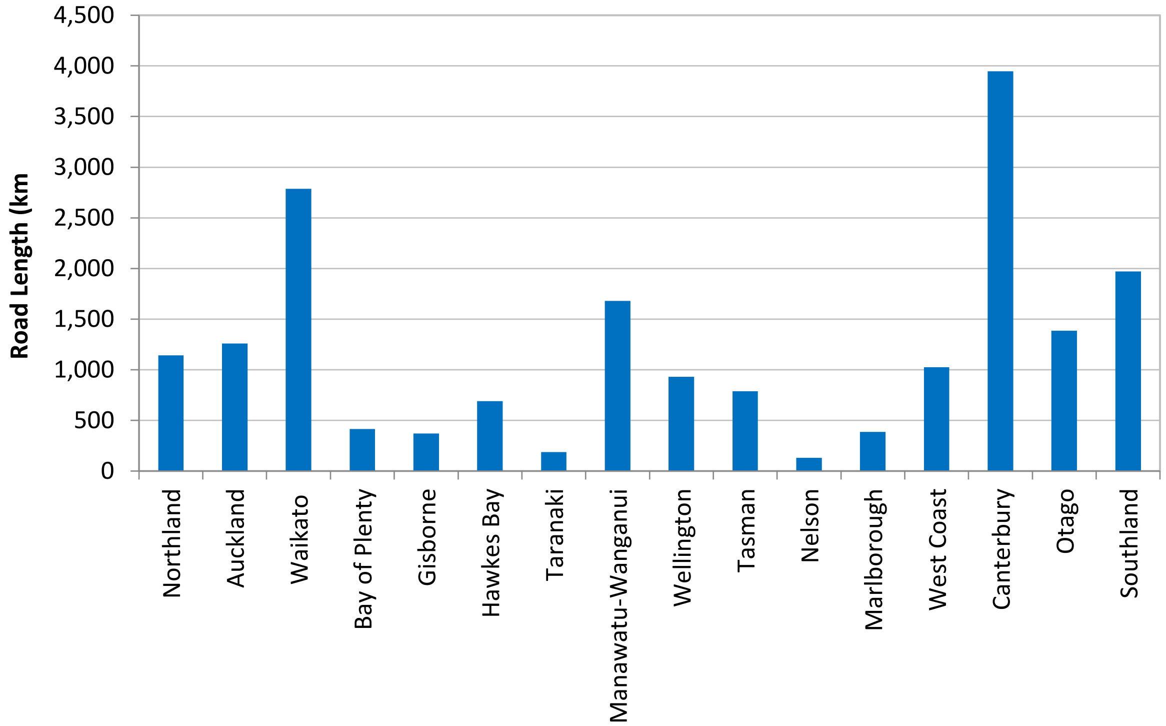


Figure 3-8: Region level road network exposure in the FLHA.

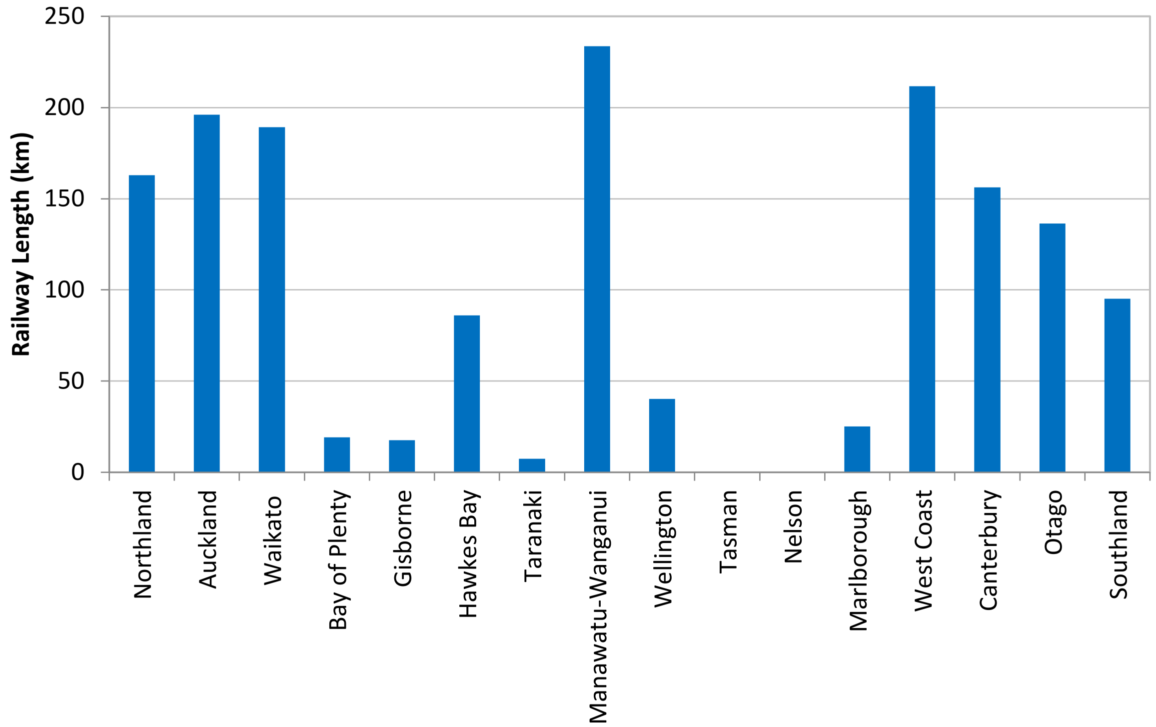


Figure 3-9: Region level railway network exposure in the FLHA.

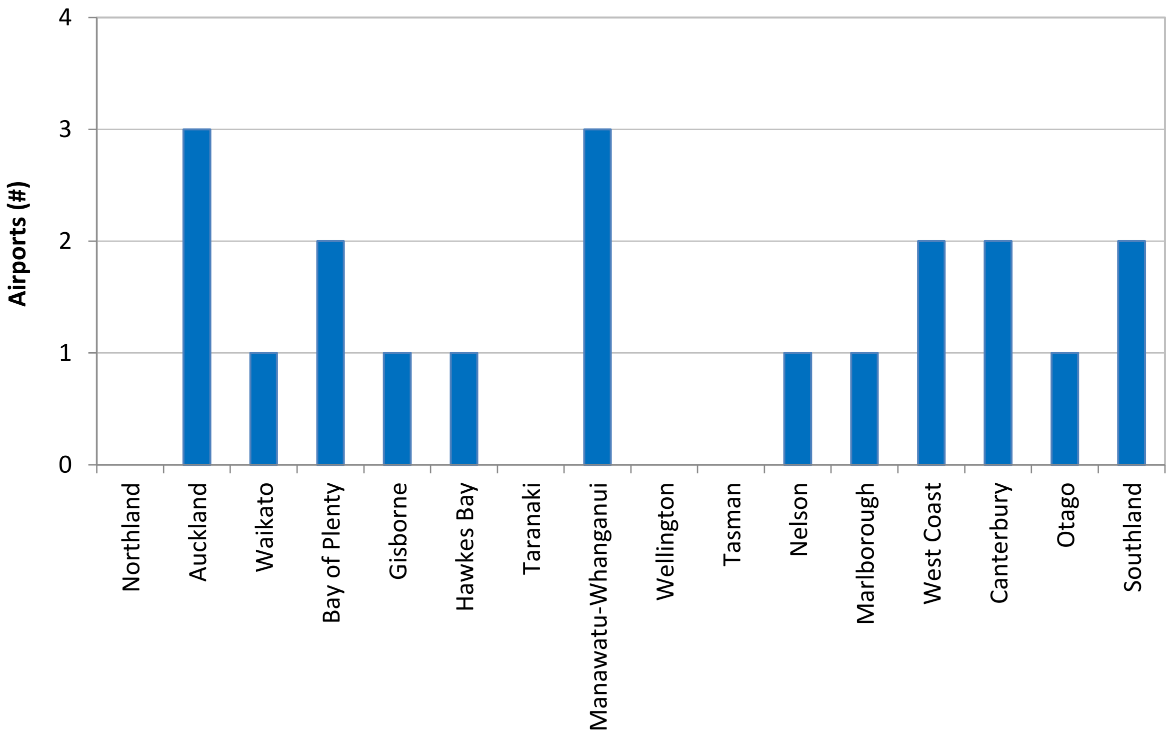


Figure 3-10: Region level airport exposure in the FLHA.

3.5 Electricity infrastructure

3.5.1 National

Almost 3,400 km of national grid transmission lines cross the FLHA. These 'lines' are supported in the FLHA by 5,848 structures and connected to 49 sites (e.g. substations) on flood prone land.

3.5.2 Regions and territories

Canterbury, Waikato and Manawatu-Wanganui have the highest FLHA transmission line coverage over the FLHA (Figure 3-11). These are supported by 672 (Canterbury), 1,262 (Waikato) and 1,006 (Manawatu-Wanganui) and structures and 10 (Canterbury), 8 (Waikato), and 4 (Manawatu-Wanganui) sites in the FLHA (Figure 3-12 and Figure 3-13).

Territory level exposure of national electricity grid assets is highest in Waipa District (376 km lines, 415 structures, 3 sites), Auckland (214 km lines, 243 structures, 4 sites), and Marlborough District (206 km lines, 160 structures, 1 site).

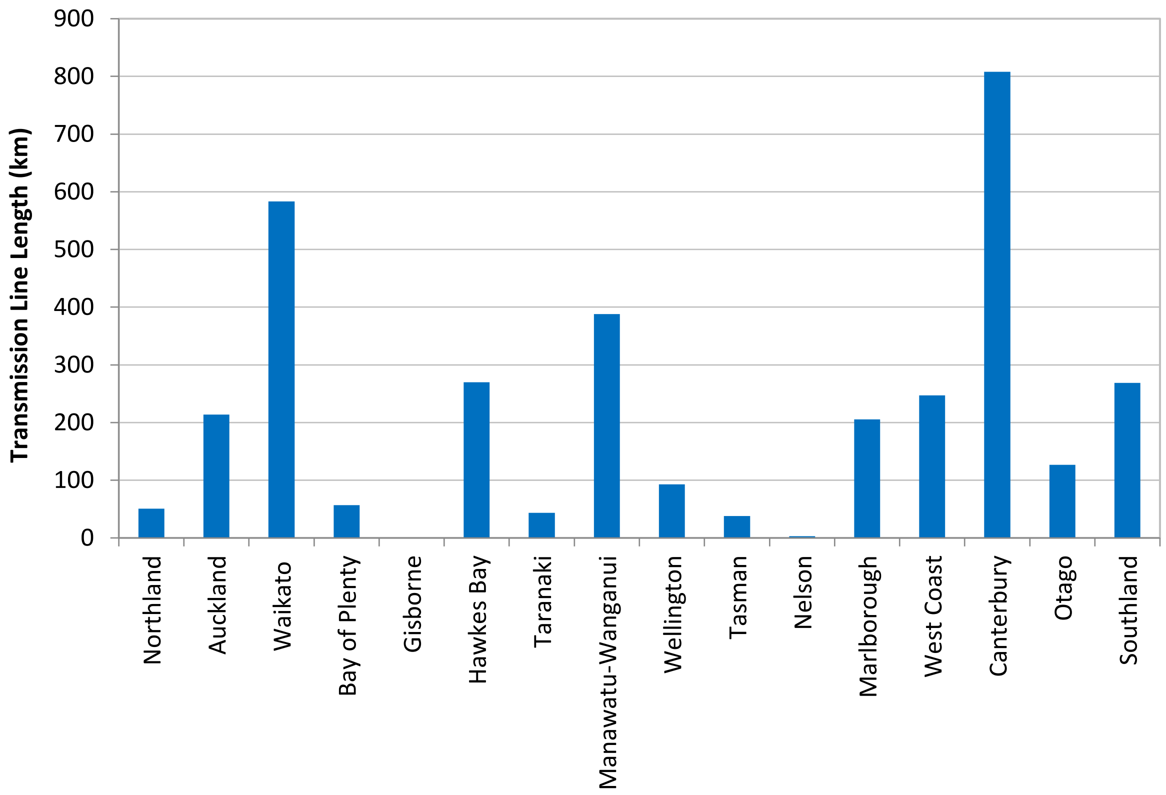


Figure 3-11: Region level national electricity grid transmission line exposure in the FLHA.

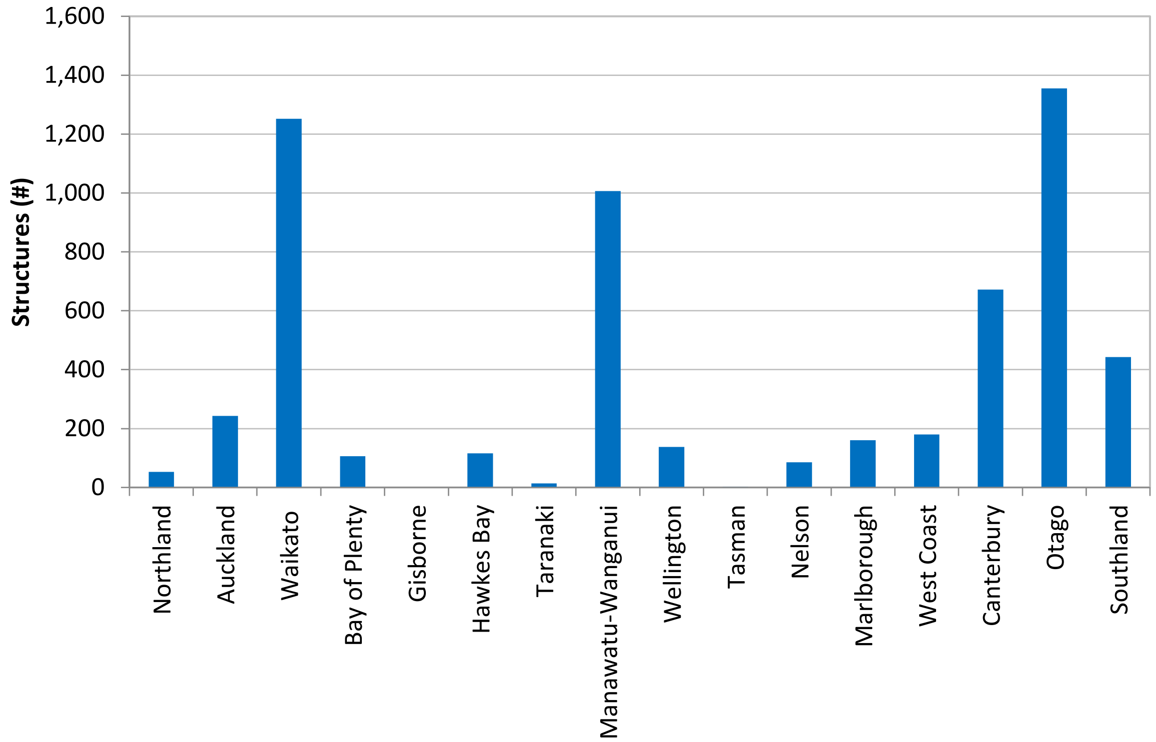


Figure 3-12: Region level national electricity grid structure exposure in the FLHA.

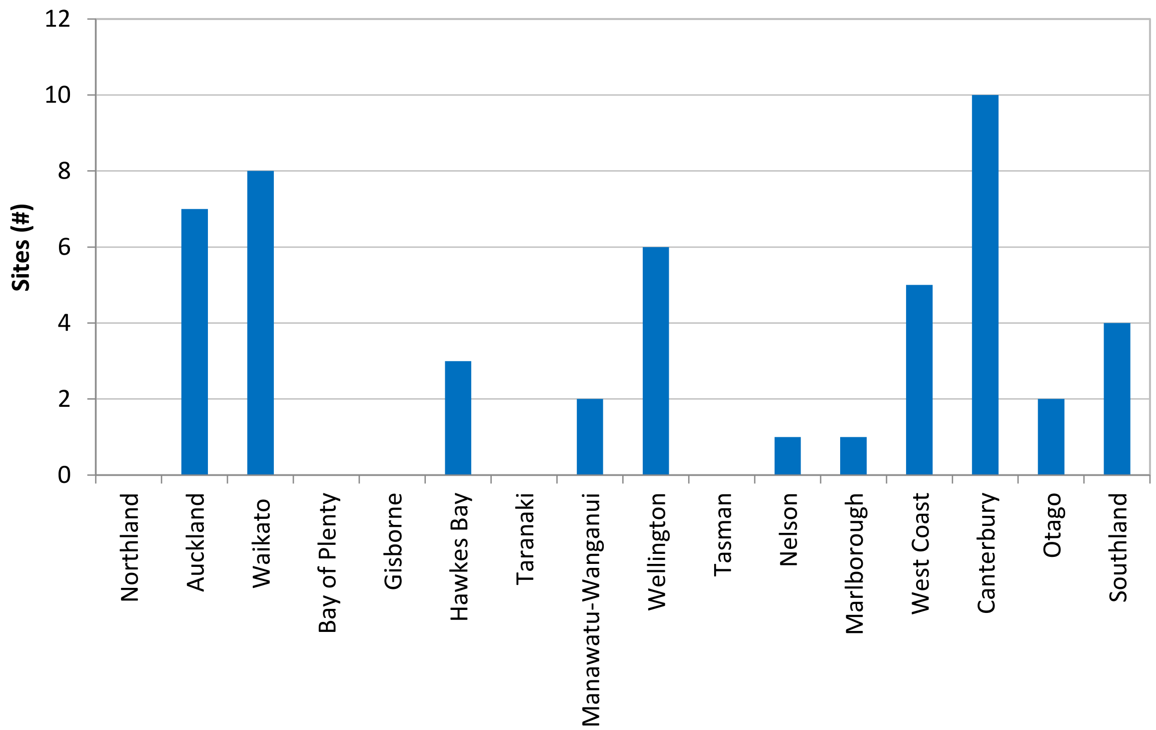


Figure 3-13: Region level national electricity grid site exposure in the FLHA.

3.6 Three-waters infrastructure

3.6.1 National

Three-waters infrastructure networks and components in this study include potable water, wastewater and stormwater nodes and pipelines. Overall three networks, 442,499 nodes and 21,173 km of pipelines lie within the FLHA. Potable water components are most highly exposed with 190,494 nodes and 8,542 km of pipelines. Wastewater pipelines (6,912 km) exceeds stormwater pipeline (5,720 km) exposure, though stormwater nodes have greater exposure (161,983) than wastewater nodes (90,022).

3.6.2 Regions and territories

New Zealand regions with the most populous urban centres, Auckland, Wellington and Christchurch, are observed to have the highest pipeline exposure for each of the three-waters. The highest node exposure also occurs in Auckland and Wellington. Node data for the Canterbury region was unavailable for this study, but Canterbury's significant three-waters pipeline exposure suggests node exposure for each of the three-waters will be relatively high amongst New Zealand's regions.

Auckland (1,448km pipelines; 40,576 nodes), Wellington (893 km pipelines; 37,620 nodes) and Canterbury (2,204 km pipelines) have the largest potable water network exposure in the FLHA (Figure 3-14; Figure 3-15). Gisborne and Nelson have the highest proportion of total network exposure, with more than 30% of nodes and pipelines exposed. Potable water network exposure at a territory level (excluding Auckland) is highest in Christchurch City (1,743 km pipelines), Dunedin City (703 km pipelines; 26,900 nodes), and Hamilton City (502 km pipelines; 5,351 nodes).

Wellington (1,021 km pipelines; 20,870 nodes) and Auckland (1,448km pipelines; 31,933 nodes) have the largest overall wastewater network exposure in the FLHA (Figure 3-14; Figure 3-15). Canterbury also has more than 1,000km of pipeline crossing flood prone land. Tasman has the highest proportion of total network exposure, with over 45% of nodes and pipelines exposed. Christchurch City and Lower Hutt City have more than 600 km of pipeline exposed, the most at territory level.

Auckland's stormwater network has 1,513 km and 73,656 nodes located in the FLHA (Figure 3-15). Wellington also has over 1,000 km of pipelines and 20,000 nodes located on flood prone land. The highest proportion of total network exposure occurs in Gisborne region with 43% of pipes (100 km) and 42% of nodes (3,871) in the FLHA. Christchurch City and Lower Hutt City each have more than 500 km of pipelines in the FLHA while Tauranga City and Nelson City have highest node exposure at territory level, each with approximately 12,000.

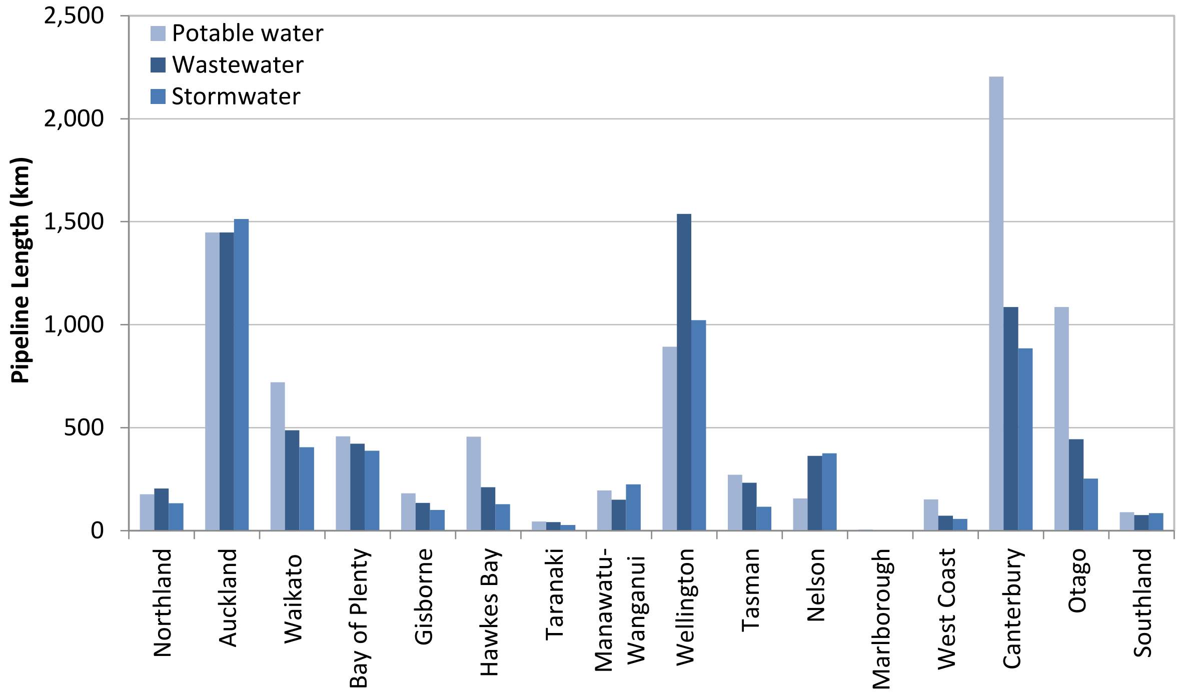


Figure 3-14: Region level three-waters network pipeline (km) exposure in the FLHA. Note: for this study, limited three-waters network pipeline data was available for Marlborough region.

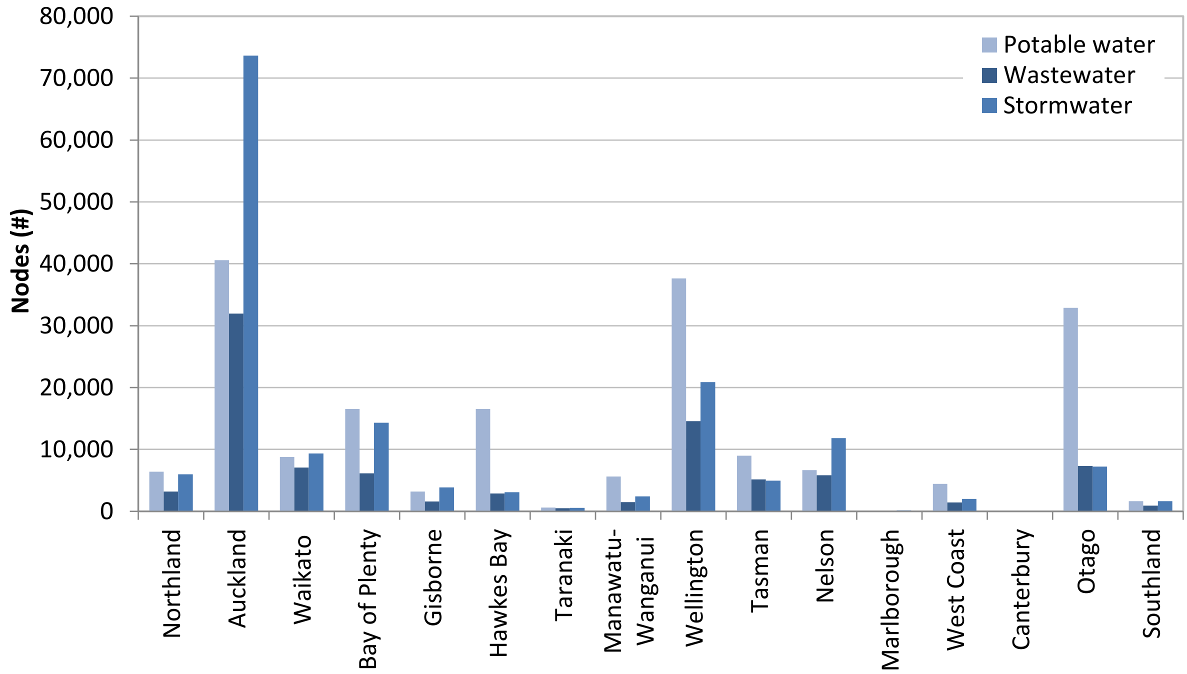


Figure 3-15: Region level three-waters network node exposure in the FLHA map. Note: for this study, three-waters network node data was not available for Canterbury region, while limited data was available for Marlborough region.

3.7 Land cover

3.7.1 National

The FLHA covers an estimated 20,883 km^2 land area. The South Island (12,152 km^2) has a larger FLHA land area compare to the North Island (8,730 km^2). Production land (15,190 km^2) is most highly exposed, nearly three-times the area of natural or undeveloped land cover types (5,335 km^2). Built land cover identified in the FLHA is 358 km^2.

3.7.2 Regions and territories

Canterbury, Waikato, Southland and West Coast each have over 2,000 km^2 of land in the FLHA. Northland, Manawatu-Wanganui and Otago also have more than 1,000 km^2 of land exposed.

The Canterbury region has the largest amount of built land cover exposed in the FLHA with 112 km^2 (Figure 3-16). Built land area in New Zealand's other most populous regions, Waikato, Auckland and Wellington are also highly exposed, each with more than 25 km. Territories in these regions containing the main population centres such as, Christchurch City (85 km^2) and Auckland (29 km^2), have the largest land exposure.

Extensive production land exposure to flood hazards is identified in key diary and pastoral production regions including: Canterbury (2,991 km^2), Waikato (2,288 km^2) and Southland (2,180 km^2) (Figure 3-17). Four territories in these regions, Southland District, Waikato District, Selwyn District and Ashburton District, have more than 500 km^2 of production land exposed. Southland District has the largest exposed land area with 1,907 km^2. West Coast has the largest proportion of production land (48%) in the FLHA at regional level.

The South Island has more than double the North Islands natural or undeveloped land cover exposure. West Coast region has the largest area exposed with 1,207 km^2, followed by Southland (979 km^2) and Canterbury (949 km^2) (Figure 3-18). With these regions, Southland District, Westland District, Grey District, Buller District and Selwyn District each have over 200 km^2 of natural or undeveloped land cover types exposed to flood hazards.

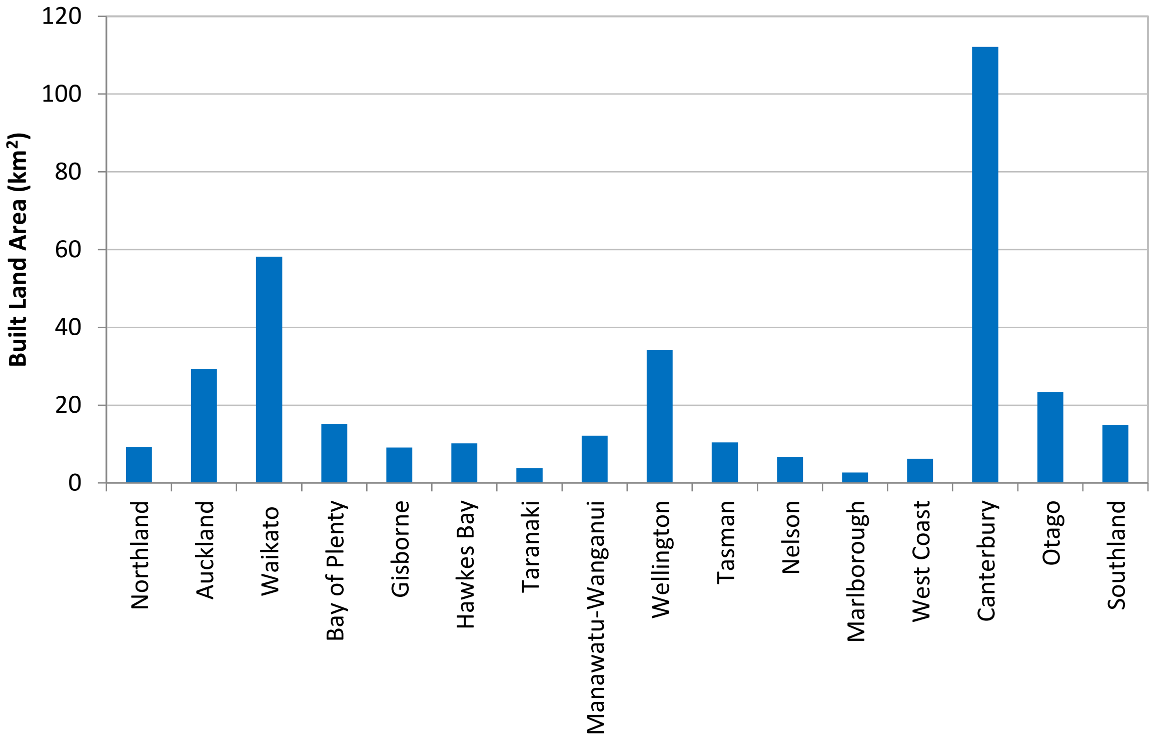


Figure 3-16: Region level built land exposure in the FLHA map.

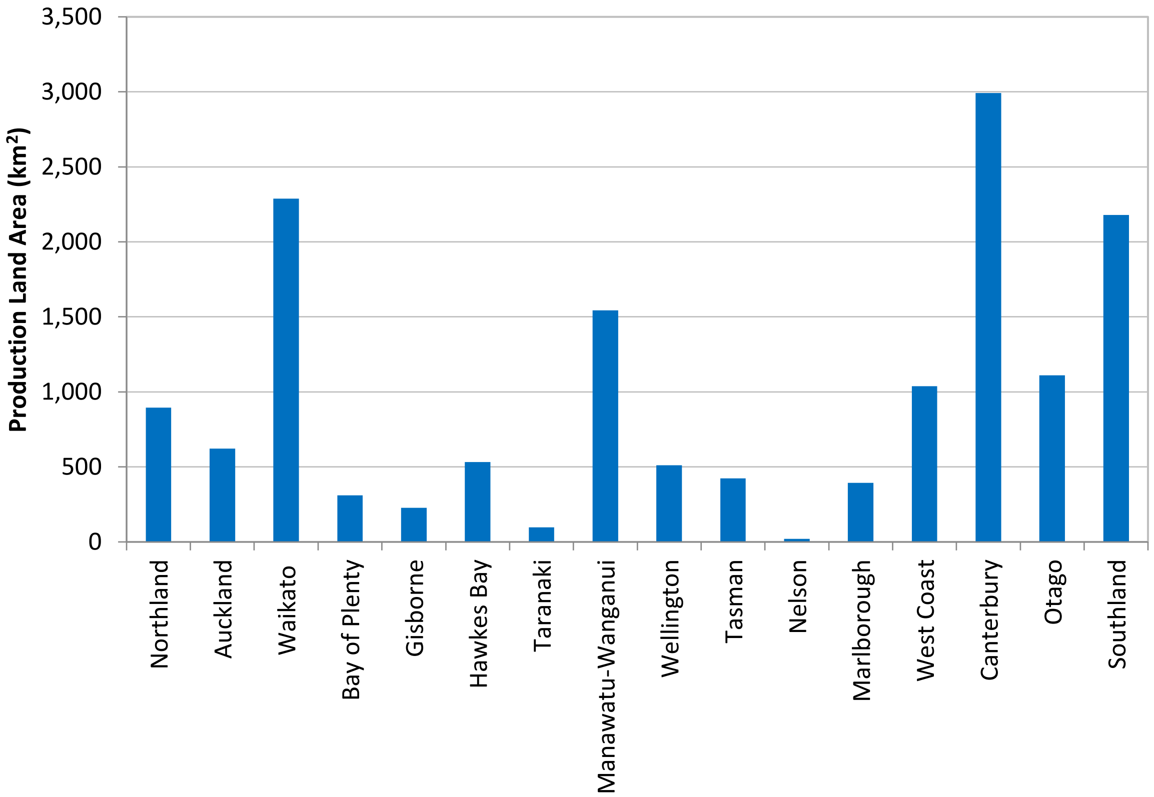


Figure 3-17: Region level production land exposure in the FLHA map.

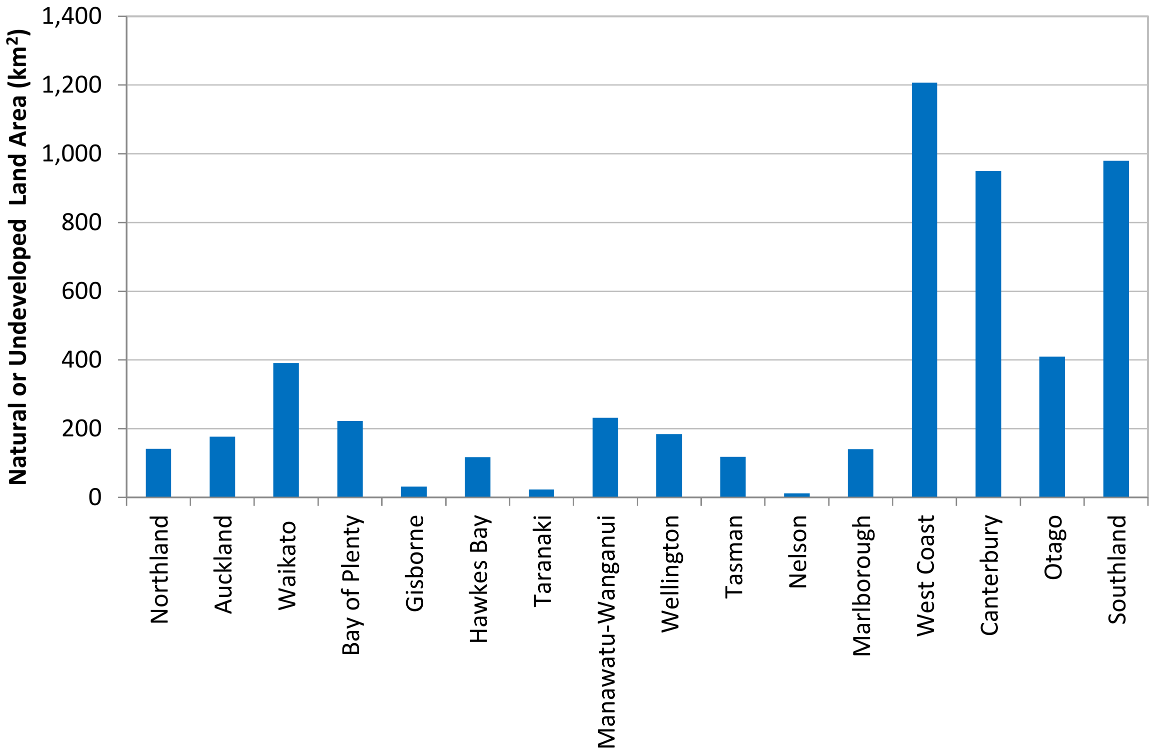


Figure 3-18: Region level natural or undeveloped land exposure in the FLHA map.

3.8 Mean annual flood response to regional climate change projections

Elements at risk in the FLHA could be exposed to more frequent and/or higher magnitude flood hazard under future climate conditions.

The maps used to identify the FLHA do not specifically represent land prone to flood hazards under recent representative concentration pathway (RCP) scenarios for future greenhouse gas concentrations. Projected mean annual flood (MAF) discharge change under future RCP's (Collins and Zammit, 2016) represented at Strahler 3 catchment levels are therefore, used here as a proxy to indicate the potential flood hazard exposure sensitivity of elements identified in the FLHA.

This section presents MAF discharge sensitivity in response to RCP scenarios 2.6 and 8.5 for time horizons: 2036-2056 and 2086-2099. Elements at risk in the FLHA are aggregated for their corresponding Strahler 3 catchment and reported here for MAF discharge changes: >20%, 0-20%, 0--20% and >-20%.

Tabulated results for RCP scenarios 2.6 and 8.5 are presented in Sections 3.8.1 and 3.8.2 respectively for exposed populations and buildings (count and replacement value). Results for other built assets and land cover, along with RCP scenarios 4.5 and 6.0 are provided as a digital appendix to this report (see Appendix A).

3.8.1 Population

The RCP 2.6 (2036-2056) scenario shows FLHA populations exceeding 1,000 reside in Waikato, Canterbury and Nelson in catchments where a >20% MAF increase could occur (Table 3-2). Over longer RCP 2.6 timeframes (2056-2099) and 8.5 (2036-2056), these catchments could potentially experience a lower MAF discharge.

Table 3-2: Regional level FLHA usually-resident population totals identified in catchments experiencing MAF change for scenario RCP 2.6.

Region	2036-2056				2086-2099			
	>20%	0-20%	-20-0%	>-20%	>20%	0-20%	-20-0%	>-20%
Auckland	67	33,477	20,949	49	0	31,501	22,901	141
Bay of Plenty	0	10,364	7,370	0	0	12,715	5,019	0
Canterbury	2,378	113,350	41,758	382	0	13,114	100,916	43,838
Gisborne	0	193	12,737	2,265	0	5,135	9,940	121
Hawkes Bay	0	6,925	9,510	913	0	6,717	9,531	1,101
Manawatu-Whanganui	38	17,853	5,490	52	158	9,693	13,501	79
Marlborough	4	1,946	2,629	22	0	886	3,599	117
Nelson	1,165	2,709	6,257	38	0	1,184	8,739	248
Northland	6	2,700	10,815	111	0	1,863	11,001	769
Otago	3	30,371	1,629	6	0	4,243	26,919	847
Southland	172	15,799	1,614	0	0	760	16,722	103
Taranaki	0	2,059	38	0	9	2,082	6	0
Tasman	888	8,804	8,467	1,696	8	4,390	12,508	3,019
Waikato	2,097	51,231	29,616	0	0	58,122	24,579	242
Wellington	0	24,114	24,946	17	0	6,158	42,914	0
West Coast	0	6,444	2,521	0	0	7,279	1,630	57

Table 3-3: Regional level FLHA usually-resident population totals identified in catchments experiencing MAF change for scenario RCP 8.5.

Region	2036-2056				2086-2099			
	>20%	0-20%	-20-0%	>-20%	>20%	0-20%	-20-0%	>-20%
Auckland	0	29,684	24,493	365	0	0	4,066	50,476
Bay of Plenty	0	1,958	15,757	19	0	28	11,274	6,432
Canterbury	909	44,058	98,438	14,463	13,560	2,166	55,607	86,535
Gisborne	0	1,914	13,011	271	0	0	2,348	12,848
Hawkes Bay	0	2,819	13,608	921	0	102	14,777	2,470
Manawatu-Whanganui	4	4,425	18,826	177	0	2,092	11,046	10,293
Marlborough	38	51	4,290	223	0	3	837	3,762
Nelson	0	557	8,740	873	0	0	1,442	8,728
Northland	0	349	11,776	1,507	0	0	9,333	4,299
Otago	4	14,472	17,058	475	4,716	20,203	5,985	1,105
Southland	172	12,220	5,192	0	0	555	16,663	358
Taranaki	0	38	2,059	0	0	28	2,065	0
Tasman	316	1,144	12,752	5,714	385	762	4,216	14,563
Waikato	0	20,917	56,351	5,675	0	9	34,324	48,611
Wellington	0		49,007	65	0	325	45,477	3,275
West Coast	42	3,893	4,968	61	2,439	1,819	829	3,878

In scenario RCP 8.5 (2056-2099), approximately 25% (2,439) of FLHA populations in West Coast region reside in catchments where a >20% MAF increase could occur (Table 3-3). Canterbury (13,560) and Otago (4,716) have larger FLHA populations in catchments with an >20% MAF increase. Waikato region observes <20% MAF increase both RCP 8.5 scenarios, despite a >20% MAF increase in RCP 2.6 (2036-2056).

3.8.2 Buildings

Over 1,000 FLHA buildings in Canterbury and Waikato (each region exceeding NZD$300 M in total replacement value) are in catchments that could experience >20% MAF increase under RCP 2.6 2036-2056 (Table 3-4). Auckland's 93 buildings in catchments with this MAF change, have a relatively high estimated replacement value of NZD$247 M. Gisborne and Tasman regions have more than 1,000 buildings in catchments where a >20% MAF reduction could be experienced in 2036-2056. For the RCP2.6 2086-2099, relatively few buildings are in catchments with >20% MAF increase (Table 3-5).

An opposing trend to RCP 2.6 is observed with RCP 8.5 scenarios. In RCP8.5 2036-2056, relatively few buildings are in catchments with >20% MAF increase (Table 3-6). Canterbury (7,481) and Nelson (545) have buildings replacement values exceeding NZD$100 M located in these catchments for RCP8.5 2086-2099 (Table 3-7). In other regions, catchments experiencing a >20% MAF increase have relatively few FLHA buildings with only Tasman and West Coast exceeding 100 buildings.

Table 3-4: Regional level FLHA building totals identified in catchments experiencing MAF change for scenario RCP 2.6.

Region	2036-2056				2086-2099			
	>20%	0-20%	-20-0%	>-20%	>20%	0-20%	-20-0%	>-20%
Auckland	93	8,833	0	37	0	13,659	9,590	116
Bay of Plenty	0	5,350	4,256	0	0	7,738	1,868	0
Canterbury	1,393	70,860	24,626	231	1	7,483	62,307	27,319
Gisborne	0	178	9,691	1,718	0	3,762	7,709	116
Hawkes Bay	0	5,286	7,565	552	0	5,742	6,956	705
Manawatu-Whanganui	61	19,770	5,319	82	188	11,240	13,685	119
Marlborough	2	1,495	2,164	25	0	824	2,737	125
Nelson	545	1,265	4,109	24	0	555	5,281	107
Northland	5	2,620	9,463	96	0	1,574	9,783	827
Otago	0	15,986	630	0	0	3,367	13,249	0
Southland	140	11,613	1,305	1	0	745	12,198	116
Taranaki	0	2,110	43	0	11	2,135	7	0
Tasman	477	4,142	4,467	1,487	15	2,110	6,308	2,140
Waikato	1,206	36,893	15,874	0	0	37,583	16,169	221
Wellington	0	13,307	13,569	35	0	3,464	23,437	10
West Coast	0	4,086	1,697	0	0	4,621	1,135	27

Table 3-5: Regional level FLHA building totals identified in catchments experiencing MAF change for scenario RCP 8.5.

Region	2036-2056				2086-2099			
	>20%	0-20%	-20-0%	>-20%	>20%	0-20%	-20-0%	>-20%
Auckland	0	16	20,967	2,382	0	274	22,589	502
Bay of Plenty	0	2,184	7,376	46	0	1,207	8,270	129
Canterbury	11	3,411	83,882	9,806	7,481	525	49,893	39,211
Gisborne	0	4	11,381	202	0	799	10,676	112
Hawkes Bay	0	595	12,738	70	0	8,061	5,317	25
Manawatu-Whanganui	0	2,407	22,312	513	10	6,118	18,665	439
Marlborough	0	38	2,916	732	1	206	3,384	95
Nelson	0	0	3,815	2,128	545	3,519	1,853	26
Northland	0	0	9,855	2,329	0	2,291	8,758	1,135
Otago	7	8,301	8,297	11	7	2,281	14,319	9
Southland	0	4,202	8,857	0	0	22	12,417	620
Taranaki	0	3	2,150	0	11	395	1,747	0
Tasman	11	497	5,487	4,578	151	3,605	4,904	1,913
Waikato	0	8,269	36,488	9,216	0	1,774	44,586	7,613
Wellington	0	0	26,832	79	0	2,307	24,570	34
West Coast	0	3,042	2,645	96	126	2,505	3,069	83

Table 3-6: Regional level FLHA building replacement value (NZD$ 2016 millions) totals identified in catchments experiencing MAF change for scenario RCP 2.6.

Region	2036-2056				2086-2099			
	>20%	0-20%	-20-0%	>-20%	>20%	0-20%	-20-0%	>-20%
Auckland	237	1,454	0	116	0	4,266	1,882	403
Bay of Plenty	0	1,414	952	0	0	1,764	603	0
Canterbury	338	3,129	1,809	61	0	98	3,788	1,816
Gisborne	0	48	1,824	330	0	612	1,572	18
Hawkes Bay	0	1,357	1,862	113	0	1,374	1,814	145
Manawatu-Whanganui	12	2,173	1,087	13	32	2,375	2,024	20
Marlborough	1	395	586	4	0	297	669	19
Nelson	141	328	1,341	4	0	143	1,643	28
Northland	0	469	2,041	17	0	295	2,107	125
Otago	0	3,365	167	0	0	1,102	3,730	0
Southland	36	1,947	338	0	0	188	2,667	29
Taranaki	0	400	7	0	2	404	1	0
Tasman	150	1,179	1,158	285	3	596	1,703	470
Waikato	305	2,267	697	0	0	2,115	868	50
Wellington	0	1,959	1,051	6	0	1,008	2,498	2
West Coast	0	1,083	406	0	0	1,192	293	4

Table 3-7: Regional level FLHA building replacement value (NZD$ 2016 millions) totals identified in catchments experiencing MAF change for scenario RCP 8.5.

Region	2036-2056				2086-2099			
	>20%	0-20%	-20-0%	>-20%	>20%	0-20%	-20-0%	>-20%
Auckland	0	6	3,466	1,701	0	83	3,958	720
Bay of Plenty	0	493	1,867	8	0	192	2,153	22
Canterbury	3	1,141	3,990	859	217	124	3,174	1,886
Gisborne	0	0	2,173	28	0	139	2,047	16
Hawkes Bay	0	184	2,392	16	0	1,998	1,327	8
Manawatu-Whanganui	0	541	2,644	95	1	1,301	1,838	79
Marlborough	0	9	805	171	0	60	909	16
Nelson	0	0	1,190	623	141	1,019	646	8
Northland	0	0	2,096	431	0	512	1,796	219
Otago	1	4,046	2,578	2	1	565	3,426	2
Southland	0	1,419	2,787	0	0	4	2,110	174
Taranaki	0	1	406	0	2	73	332	0
Tasman	1	233	1,386	1,151	66	1,141	1,184	381
Waikato	0	2,214	1,773	2,633	0	382	2,509	2,084
Wellington	0	0	3,009	14	0	739	2,740	6
West Coast	0	752	720	18	47	612	815	15

3.8.3 Transport infrastructure

Roads

Marlborough (147 km) and Canterbury (112 km) regions have the highest FLHA road exposure in catchments that could experience >20% MAF increase in RCP 2.6 2036-2056. In these regions, road exposure reduces to almost zero for these catchments in RCP 2.6 2086-2099. In most regions, FLHA roads in this scenario are more likely to be in catchments that could have a >20% MAF decrease.

In RCP 8.5 2036-2056, Canterbury also has the highest FLHA road network (163 km) in catchments with a >20% MAF increase. The regions FLHA roads in these catchments with this MAF change increases slightly (175 km) by 2086-2099, while Otago's FLHA roads increase by almost 100 km. In other regions, FLHA roads in Auckland, Waikato and Manawatu-Whanganui each exceed 500 km catchments with an estimated >20% MAF decrease.

Railway

New Zealand's FLHA railway network has 21.9 km in catchments where a >20% MAF increase is estimated in RCP 2.6 2036-2056, reducing to less than 10 km by 2086-2099.

Canterbury is the only region with FLHA railway (20 km) in catchments with an estimated >20% MAF increase in RCP 8.5 2036-2056. The regions FLHA railway exposure decreases 50% for this MAF change by 2086-2099. For this period, 90 km of West Coast FLHA railway is in catchments with an estimated >20% MAF increase.

Airports

Minimal areas of FLHA airport land are in catchments where a >20% MAF increase is estimated for any RCP scenario. RCP 8.5 2086-2099 shows only 1 km^2 of land located in these catchments, mostly in West Coast region (0.7 km^2).

3.8.4 Electricity infrastructure

Lines

Approximately 149 km of transmission lines in the FHLA are in catchments with an estimated >20% MAF increase in RCP 2.6 2036-2056. Most FHLA lines are in the Waikato region (112 km). The regions FLHA lines in these catchments reduces to zero in scenarios RCP 8.5 2036-2056 and 2086-2099. Across New Zealand, only 46 km of lines is identified in in catchments with a >20% MAF increase in RCP 8.5 2086-2099, compared to 1,394 km where a >20% MAF decrease is expected.

Structures

Electrical network structures in the FLHA are mostly located in Waikato (229) and Canterbury (50) catchments where a >20% MAF increases are estimated in RCP 2.6 2036-2056. In Canterbury, FLHA structures increase to almost 100 by RCP 8.5 2036-2056, whereas Waikato has a larger number of structures (145) in catchments experiencing a >20% MAF decrease.

Sites

Nelson is the only region with a site located in a catchment with an estimated >20% MAF increase (RCP 2.6 2036-2056). In RCP 8.5 2086-2099, fifteen sites occurring in the FLHA across New Zealand in catchments where a >20% MAF decrease is estimated.

3.8.5 Three waters infrastructure

Potable water

FLHA potable water network components in Canterbury, Nelson and Tasman are most extensive in catchments susceptible to a >20% MAF increase in RCP 2.6 2036-2056. Although Canterbury has 37 km of pipelines in these catchments, this reduces to zero for the 2086-2099 period. FLHA pipelines in the regions catchments where a >20% MAF decrease is estimated is 557 km.

Under RCP 8.5 scenarios, relative to other regions, Canterbury's FLHA pipelines are most extensive in catchments experiencing a >20% MAF increase. The regions FLHA pipelines increase from 43 km in 2036-2056 to 131 km in 2086-2099. Over these periods, Otago (+85 km pipelines; +3,826 nodes) and West Coast regions (+31 km pipelines; +336 nodes) also observe considerable increases in FLHA pipeline and node components located in these catchments.

Waste water

FLHA wastewater pipelines and nodes in catchments with a >20% MAF increase in RCP 2.6 2036-2056 are mostly located Canterbury, Nelson and Tasman. Like potable water, FLHA components reduce to almost to zero for each region in the 2086-2099 period.

Under RCP 8.5 scenarios, Canterbury (9.9 km pipelines) and Tasman (7.2 km pipelines; +207 nodes) have the highest FLHA wastewater components located in catchments sensitive to a >20% MAF increase in the 2036-2056 period. In these catchments, Canterbury's FLHA pipelines increase by 55 km in 2086-2099, while Otago has an additional 46km of pipelines and 805 nodes. At this time, considerable FLHA wastewater component exposure in Auckland (598 km pipelines; 1,626 nodes), Nelson (249km pipelines; 3,864 nodes) and Tasman (199 km pipelines; 4,426 nodes) regions is identified in catchments with an estimated >20% MAF decrease.

Stormwater

Auckland, Nelson and Tasman regional stormwater networks have FLHA pipelines and nodes located in catchments with a >20% MAF increase in RCP 2.6 2036-2056. These FLHA components are more likely to be in catchments experiencing a >20% MAF decrease in RCP 8.5 2086-2099. Canterbury (45 km pipelines[10]) and Otago (25 km pipeline; 734 nodes) have the most extensive FLHA stormwater networks exposure in catchments with a >20% MAF increase for this scenario.

3.8.6 Land cover

Built land

In RCP 2.6 scenarios, less the 5 km^2 of New Zealand's FLHA built land occurs in catchments with a >20% MAF increase. Relatively small built land extents are also observed for RCP 8.5 2036-2056. For the 2086-2099 period, Canterbury has more than 6 km^2 FLHA built land in these catchments. Considerable built land (146 km) extent across New Zealand is identified in catchments where a >20% MAF decrease is estimated for RCP 2.6 2086-2099.

Production land

FLHA productive land is most extensive in Canterbury (85 km^2) and Waikato (37 km^2) catchments experiencing a >20% MAF increase for RCP 2.6 2036-2056. FLHA land decreases to just over 23 km^2 for New Zealand by 2086-2099 and is almost zero for both Canterbury and Waikato for this period. Canterbury has more than 880 km^2 of FLHA production land in catchments with an estimated >20% MAF decrease for RCP 2.6 2036-2056.

FLHA production land exposed is most extensive in catchments susceptible to MAF increase in RCP 8.5 scenarios. In the 2036-2056 period, New Zealand FLHA production land for catchments with a >20% MAF increase is 221 km^2, mostly in Canterbury (148 km^2) and West Coast regions (41 km^2). , New Zealand's total FLHA production land increases to 709km for the 2086-2099 period, with 514 km^2 on the West Coast.

Natural or undeveloped land

FLHA natural or undeveloped land is most extensive in Manawatu-Whanganui, Tasman, Canterbury, West Coast, Otago and Southland catchments susceptible to MAF increases under future RCPs. West Coast has the largest FLHA natural or undeveloped land area for all RCP scenarios, with 512 km^2 in catchments with an estimated >20% MAF increase for RCP 8.5 2086-2099

3.8.7 Caveat

This section uses MAF changes under climate change s a proxy for sensitivity of flood risk to climate change. However, climate change effects on more extreme scenarios do not necessarily follow those

[10] Node data not available for this study.

for MAF. Far more work is needed to properly understand the climate change effects on flood hazard and risk and the associated uncertainties.

4 Conclusions and Recommendations

4.1 Conclusions

This study is a first attempt to enumerate New Zealand's population and asset exposure in fluvial and pluvial floodplains.

A consistent flood hazard map for New Zealand is not available at an appropriate resolution for mapping floodplain populations and assets. The absence of national map was addressed in this study by creating a 'composite' flood hazard area map (FLHA) from modelled and historic flood hazard maps and flood prone soil maps, publicly available in August 2018. The FLHA represents known or mapped floodplains and was deemed sufficient for a first attempt at enumerating national, region and territory exposure of floodplain populations, buildings, infrastructure (transport, electricity and three-waters) and land cover. Whilst the reported enumerations are acceptable for an order-of-magnitude national-scale exposure assessment, the uncertainty is still large, even at this scale. More detailed flood hazard modelling and analysis is needed to reduce this uncertainty and to allow for higher resolution analysis.

New Zealand has a potential FLHA land area of over 20,000km^2, occupied by a usually-resident population of approximately 675,000. The FLHA has over 411,000 buildings with a NZD$135 B replacement value (2016 replacement values). FLHA infrastructure network components include more than 19,000 km of roads, over 1,500 km of railway, 20 airports, 3,397 km of electricity transmission lines and more than 21,000 km of three-waters pipelines.

Regional level population and built asset FLHA exposure is frequently highest in New Zealand's three most populous regions: Auckland, Wellington and Canterbury. Canterbury has the highest FLHA-affected population, buildings, roads, electricity network components (transmission lines, structures and sites), potable water pipelines and both built and production land cover. The region's FLHA-affected population, buildings, infrastructure and built land is mostly located in Christchurch City. Auckland has the highest three-water node FLHA exposure at region level. Manawatu-Wanganui FLHA railway exposure is more extensive than exposed railway in the three most populous regions. Natural or undeveloped FLHA land is most exposed in the West Coast region.

In the absence of a national-scale flood hazard model that accounts for climate change effects, catchment level (Strahler 3) mean annual flood (MAF) discharge change in response to four representative concentration pathway (RCP) scenarios for 2036-2056 and 2086-2099 periods, are used as a proxy indicator to identify the potential flood hazard exposure sensitivity of elements identified in the FLHA to changing MAF conditions. At region level, FLHA-affected populations and assets are predominantly in catchments with ±20% MAF change for all RCP scenarios, while relatively small proportions located with catchments >20% MAF change in scenarios RCP2.6 2036-2056 and RCP 8.5 2086-2099. Changes in MAF, however, may not correlate with changes to more extreme scenarios. Future mapping of climate change effects on flood hazards is needed which consider the effects of both rainfall and sea level rise more comprehensively.

This report is an initial assessment of the exposure of New Zealand to flood inundation. Not all assets are considered and only exposure is considered as the FLHA only shows potential flood-prone regions. Any specific event would only flood part of the FLHA, and not all exposed buildings reported in this study would be exposed and/or sustain damage. The potential direct and indirect economic loss for flood exposed buildings were not considered in this study and should be included in future national flood damage assessments.

This study highlights the need for a more comprehensive assessment of New Zealand's flood hazard and risk. Consistent flood hazard mapping is needed at resolutions appropriate for assessing the exposure and consequences of elements at risk to flood hazards at national-scale. Ideally this would cover a range of AEP values for both present-day fluvial and pluvial flood hazards and their response to future climate conditions. In addition, future modelling should consider potential land use change couples with climate influence on flood hazard characteristics. The absence of such a national-scale flood hazard model hinders New Zealand's ability to assess and plan for mitigating the country's exposure to flood hazards.

4.2 Recommendations for future national-scale exposure assessments

National-scale assessments of both present-day and future population and asset exposure to fluvial and pluvial flood hazards in New Zealand could be improved or extended by:

- A New Zealand flood hazard model: Develop a model suite capable of producing consistent national-scale flood hazard maps at a resolution appropriate for assessing the exposure and consequences of elements at risk. Ideally these maps should be created using high-resolution topographic data (i.e. LiDAR) and incorporate important features (e.g. stopbanks, culverts, bridges) that influence flood hazard characteristics. Flood maps should represent a range of flood hazard annual exceedance probability scenarios for present-day and future climate change scenarios. This modelling suite should be iterative, allowing for ease of updating results including improved modelling techniques, different scenarios, changes to topography and flood features (due to both improved mapping and information and actual changes to the landscape), and better understanding of changes under climate change among other things.
- Population spatial datasets: Update meshblock usually-resident populations to most recent census statistics and consider the inclusion of temporal population variations (e.g. night and day). Develop methodologies to spatially distribute populations at micro-scales (e.g. building locations, land parcels).
- Building spatial datasets: Disaggregate broad building use categories applied in this study to provide a better spatial representation of building use (e.g. resthomes, schools, emergency services etc.) in floodplains. Update building replacement values to 2018 or later values.
- Infrastructure spatial datasets: Extend the range of network infrastructure types (e.g. telecommunications) and/or components (e.g. bridges) and attributes critical to network function at local to regional levels. Include network infrastructure spatial data from territorial authorities that was missing from this study (e.g. Christchurch City three-waters nodes), when publicly available.
- Land cover spatial data: Disaggregate broad production land categories into dairy, pastoral, horticulture and viticulture categories as represented in a production land

use database such as FarmsOnline[11]. Include socio-economic attributes for land cover/or use types to quantify to relative importance of flood exposed land to the wellbeing of New Zealand.

[11] https://farmsonline.mpi.govt.nz/

5 Acknowledgements

The study was funded by the Deep South Challenge (MBIE CONTRACT NUMBER: C01X1412).

The provision of flood hazard maps either via GIS RESTful services or directly from relevant local authority is gratefully acknowledged as follows:

- Northland Regional Council
- Auckland Council
- Waikato Regional Council
- Thames Coromandel District Council
- Hamilton City Council
- Taupo District Council
- BOPLASS Ltd. (covering Bay of Plenty and Rotorua territorial authorities)
- Gisborne District Council
- Hawke’s Bay Regional Council
- New Plymouth District Council
- Horizons Regional Council
- Greater Wellington Council
- Marlborough District Council
- Nelson City Council
- Tasman District Council
- Environment Canterbury
- Christchurch City Council
- MacKenzie District Council
- Waimate District Council
- Otago Regional Council
- Dunedin City Council
- Queenstown Lakes District Council
- Clutha District Council
- Southland Regional Council

Landcare Research flood prone soil maps (FSL Flood Return Interval) provided via the LRIS portal is gratefully acknowledged for their use in this study.

The use of spatial population and asset datasets developed by the following agencies is gratefully acknowledged:

- Landcare Research: Land-Cover Database v4.1
- LINZ: NZ Railways and NZ Airports
- New Zealand Transport Agency: NZ Roads
- New Zealand Territorial and Unitary Authorities: NZ Three-waters;
    - Far North District Council
    - Whangarei District Council
    - Kaipara District Council
    - Auckland Council
    - Thames-Coromandel District Council
    - Hauraki District Council
    - Waikato District Council
    - Matamata-Piako District Council
    - Otorohanga District Council
    - Waitomo District Council
    - Western Bay of Plenty District Council
    - Tauranga City Council
    - Whakatane District Council
    - Opotiki District Council
    - Gisborne District Council
    - Wairoa District Council
    - Hastings District Council
    - Napier City Council
    - Central Hawke's Bay District Council
    - New Plymouth District Council
    - South Taranaki District Council
    - Whanganui District Council
    - Rangitikei District Council
    - Manawatu District Council

- Tararua District Council
- Horowhenua District Council
- Kapiti Coast District Council
- Porirua City Council
- Lower Hutt City Council
- Wellington City Council
- Masterton District Council
- Carterton District Council
- South Wairarapa District Council
- Tasman District Council
- Nelson City Council
- Marlborough District Council
- Kaikoura District Council
- Hurunui District Council
- Waimakariri District Council
- Christchurch City Council
- Selwyn District Council
- Ashburton District Council
- Timaru District Council
- Waimate District Council
- Waitaki District Council
- Dunedin City Council
- Clutha District Council
- Southland District Council
- Invercargill City Council

6 Glossary of abbreviations and terms

AEP	Annual Exceedance Probability (AEP) refers to the probability of a flood event occurring in any year. The probability is expressed as a percentage. For example, a flood event may be calculated to have a 1% chance to occur in any one year, is described as 1% AEP.
ARI	Annual Recurrence Interval (ARI) refers to the average annual recurrence of a flood event. The recurrence is expressed as number of years. For example, a flood event may be calculated to have a chance to occur once every one hundred years on average, is described as 1 in 100 year flood event.
B	Billion
Exposure	Population, built asset and land cover features located within spatially mapped coastal inundation extents.
GIS	Geographic Information System
LiDAR	Airborne Light Detection and Ranging (LiDAR), is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth.
LINZ	Land Information New Zealand
LRIS	Land Resource Information Systems
M	Million
MAF	Mean Annual Flood
NSD	National Soil Database
NZD	New Zealand Dollars (2016)
NZLRI	New Zealand Land Resource Information
RESTful	RESTful web service based on representational state transfer (REST) technology, an architectural style and approach to communications often used in web services development.
Strahler order	In hydrology, Strahler stream orders treat each segment of a stream or river within a river network as a node in a tree, with the next segment downstream as its parent. When two first-order streams come together, they form a second-order stream. When a second-order stream is joined by either a first or second order stream, they form a third-order stream.

7 References

Bell, R. G., King, A. B. (2009). RiskScape Project: 2004 - 2008. NIWA Science Report 2009/75. 172p

Collins, D. B. G., Zammit, C. (2016). Climate change impacts on agricultural water resources and flooding. Prepared for the Ministry for Primary Industries. November 2016. p72.

Cousins, W. J. (2009). RiskScape – development of a default assets model for Hawke's Bay. GNS Science Report 2009/50: 33.

Rouse, H. (2012). Flood risk management research in New Zealand: Where are we, and where are we going?, GNS Science Report 2012/04

Smart, G., McKercher, A. (2010). More flood disasters in New Zealand. Journal of Hydrology (NZ), 49, 2.

Tonkin & Taylor (2013). Maitai River Flood Hazard Mapping Modelling Report. Report prepared for: Nelson City Council. T&T Ref:870888. p31.

Appendix A Digital Appendix Contents

Please contact the report author or NIWA for any of the following files or information:

- Flood_Map_Information.xls
  - GIS RESTful Services
  - Flood Map Metadata
- FLHA_Population.zip
  - REG_Population.csv
  - REG_Population.shp
  - TA_Population.csv
  - TA_Population.shp
- FLHA_Buildings.zip
  - REG_Buildings.csv
  - REG_Buildings.shp
  - TA_Buildings.csv
  - TA_Buildings.shp
- FLHA_Transport.zip
  - REG_ Transport csv
  - REG_Transport.shp
  - TA_Transport.csv
  - TA_Transport.shp
- FLHA_Electricity.zip
  - REG_ Electricity.csv
  - REG_ Electricity.shp
  - TA_ Electricity.csv
  - TA_ Electricity.shp
- FLHA_Three_Waters.zip
  - REG_Three_Waters.csv
  - REG_Three_Waters.shp

- TA_Three_Waters.csv
- TA_Three_Waters.shp

- FLHA_Land_Cover.zip
  - REG_Land_Cover.csv
  - REG_Land_Cover.shp
  - TA_Land_Cover.csv
  - TA_Land_Cover.shp
- FLHA_Exposure_MAF.xls