Otago Regional Council

Otago Region Natural Hazards Exposure Analysis

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1 Executive Summary

This report presents findings of Otago Regional Council's (ORC's) first systematic analysis of natural hazard exposure for Otago. The report provides a 'stocktake' and baseline of the current understanding of natural hazard exposure for the region, and is a first iteration of analysis to quantify and map natural hazards exposure in Otago at a regional scale.

ORC's existing regional or district-scale natural hazards mapping datasets were used to identify populations and assets located in areas potentially exposed to natural hazards impact. Nine natural hazards were analysed; river and lake flooding, seismic hazards (fault rupture, liquefaction), slope stability hazards (landslide, rockfall, alluvial fans/debris inundation), and coastal hazards (storm surge inundation, tsunami and coastal erosion).

This report enumerates the exposure of three elements at risk: population, buildings and 'critical community facilities' defined as facilities which have a post-disaster function (ORC, 2021).[1] These three elements are identified based on the approach to assessing hazard consequences in the proposed Otago Regional Policy Statement 2021 (pORPS, ORC 2021). The elements at risk considered are representative of socio-economic elements at risk to natural hazard impacts, and provide an indication of the magnitude of potential natural hazards exposure.

Natural hazard exposure analysis was completed using RiskScape software, with analysis completed for the full Otago region encompassing 351 distinct geographic units, termed 'community areas', based on Statistical Areas (SA's) defined by Statistics NZ. Exposure statistics are estimated for each 'community area' and aggregated by urban area/settlement, district, and over the full region.

Key findings from this natural hazard exposure analysis for the Otago region include:

- The highest exposure for the natural hazard types considered is for river and lake flooding and liquefaction. Totals of greater than 30,000 people and buildings, including >10,000 dwellings, within the Otago region are located in areas identified as potentially subject to each of these hazards. There is also a notable spatial overlap between the geographic extents of flooding and liquefaction hazards exposure, because flood-prone areas typically comprise geologically-recent sediment deposits which may also be susceptible to liquefaction.

- The majority of exposure to river and lake flooding hazards in the region is located within the Dunedin City district, where 39 (of 117) community areas are classed having a 'high exposure'. This includes the floodplains receiving flood mitigation from ORC's Leith and Lower Taieri flood protection schemes. Population and buildings located within the 'protected' areas of ORC's flood protection schemes are considered to be potentially exposed to the hazard, as these areas could still be exposed to flooding in the case of a super-design flood event or a failure of flood protection infrastructure.

- Landslide and alluvial fan hazards each have exposure totals of greater than 5,000 people and buildings, including around 2,000 dwellings. The majority of exposure to slope stability hazards (landslide, rockfall and alluvial fan hazard) is located within the Queenstown Lakes and Dunedin City districts, with much of the exposure to these hazard types within the urban

[1] e.g. medical facilities, emergency services (police and fire), and emergency coordination/operations centres.

areas of Queenstown, Dunedin city and Wanaka. All of the community areas classed as having a 'high exposure' are located in either the Queenstown Lakes or Dunedin City districts.

- The majority of exposure to seismic hazards (active faulting and liquefaction) is located within the Dunedin City district, where the highest exposure is for the urban areas of Dunedin and Mosgiel. Totals of greater than 20,000 people and buildings in the region, including around 8,000 dwellings are located in near proximity (within 250 metres) of mapped active faults, and 40 of the community areas in the region (n = 351) are classed as having 'high exposure'. Totals of greater than 40,000 people and buildings in the region, including around 17,000 dwellings are located in locations where liquefaction is considered possible, and 78 of the community areas in the region (n = 351) are classed as having 'high exposure' to this hazard type.
- The exposure to coastal hazards (storm surge, tsunami, and coastal erosion) is much less relative to the other hazard types considered, with exposure of up to ~500 people and ~1100 buildings for each of storm surge and tsunami. Coastal erosion exposure has been analysed only for the Waitaki district, where exposure is around 100 buildings and ~40 people.
- The exposure of 90 critical community facilities in the region has been assessed for each hazard type. The greatest exposure of these facilities is to river and lake flooding (23 facilities exposed to the hazard) and liquefaction (35 facilities exposed), with some exposure also for active fault, landslide and alluvial fan hazard types.

Following completion of this regional natural hazards exposure analysis, there are two main next steps in ORC's region-wide natural hazards risk programme:

1. Natural hazards prioritisation for the Otago region, to enable a systematic identification and definition of key projects and allocation of work within the ORC Natural Hazards work programme
2. Review and possible revision of this region-wide natural hazards exposure analysis to incorporate additional or updated natural hazards mapping or elements at risk datasets. These may include incorporation of local-scale natural hazards information, use of national hazards datasets, or data for additional types of elements at risk.

2 Introduction

The Otago region is exposed to a diverse range of potential natural hazard events that may impact on people, property, infrastructure, and the wider environment; including flooding, slope stability, seismic hazards, coastal erosion, or coastal inundation due to tsunami or storm surge.

This report presents findings of Otago Regional Council's (ORC's) first systematic analysis of natural hazard exposure for Otago. The report provides a stocktake and baseline review of the natural hazard exposure for the region. The natural hazards analysis was completed as part of an ORC programme to work towards a regional-scale, spatial understanding of Otago's exposure to natural hazards.

This exposure analysis builds on the extensive natural hazard mapping and hazard assessments completed by ORC over the last 25+ years, to inform compilation of datasets with regional or district-wide coverage which provide an overview of the extents and characteristics of natural hazards. ORC's natural hazards mapping is publicly available on the ORC Natural Hazards Portal,[2] which also includes supporting information such as technical reports and photographs from previous natural hazards events. The Natural Hazards Portal provides a spatial representation of mapped natural hazards extents, which enables analysis of elements potentially exposed to those hazards to be undertaken

2.1 Purpose

The primary usage intended for this analysis and reporting is as a tool to explore the magnitude and spatial distribution of relative hazards exposure across the Otago region.

The findings from this analysis will be one source of information which will inform a regional approach developed for prioritising natural hazards adaptation. This prioritisation approach is outlined in van Woerden *et al* (2024) and will be used as a project planning tool for the ORC Natural Hazards team, to assist with enabling ORC to systematically identify and define key projects and allocation of work within the overall Natural Hazards work programme.

This natural hazard exposure analysis aligns with ORC's Strategic Directions, and plays an important role to support ORC's 2024-2034 strategic direction and vision for Otago that, "*Otago builds resilience in a way that contributes to the wellbeing of our communities and environment through planned and well- managed responses to shocks and stresses, including natural hazards.*" (ORC, 2024). More specifically, it will inform requirements of the proposed Otago Regional Policy Statement (pORPS 2021), where local authorities must "*assess the level of natural hazard risk in their region or district*" and "*continue to undertake research on the identification of natural hazard risk and amend natural hazard registers, databases, regional and/or district plans as required*." (ORC, 2021).

[2] http://hazards.orc.govt.nz

3 Methods

3.1 Natural Hazards Exposure Analysis

3.1.1 Introduction

In the context of this analysis, natural hazards exposure is the spatial overlay of the three selected community elements at risk (population, buildings, critical community facilities) with the mapped extent of potential hazard impact.

For each community area assessed in the region (n = 351), eight exposure outputs have been calculated, as summarised in Table 3.1. Natural hazard exposure is also aggregated and reported for each urban area or rural settlement, district, and the full Otago region.

These exposure values assist in understanding the scale and proportion of the element which may be directly impacted by each natural hazard.

Table 3.1: Description of exposure analysis outputs.

Element	***Description***
Population	Count of population located within the mapped hazard extent
	Proportion of population within the geographic area (statistical area, urban area/settlement, district or region) which is located within the mapped hazard extent
Buildings	Count of buildings within the mapped hazard extent (all buildings)
	Proportion of buildings within the geographic area (statistical area, urban area or rural settlement, district or region) which are located within the mapped hazard extent
	Count of buildings categorized as dwellings, within the mapped hazard extent
	Proportion of buildings categorized as dwellings within the geographic area (statistical area, urban area or rural settlement, district or region) which are located within the mapped hazard extent
Critical community facilities (CCF)	Count of critical community facilities (CCF) within the mapped hazard extent
	Proportion of critical community facilities (CCF) within the geographic area (statistical area, urban area/settlement, district or region) which are located within the mapped hazard extent

3.1.2 Exposure Classification

An exposure classification has been developed as an indicator of the overall natural hazards exposure for the three elements considered (population, buildings and critical community facilities) (Table 3.2). This table is based on the approach to assessing consequences in the proposed Otago Regional Policy Statement 2021 (pORPS, ORC 2021).

An exposure classification level has been identified for each of the 351 'community areas' in the region used for this analysis. When assessing overall natural hazards exposure level within this matrix, the exposure level class is selected on the first-past-the-post principle, in that the element with the highest exposure level sets the exposure level for that community area.

Table 3.2: Exposure level classification.

Exposure level	***Built***		***Health and Safety***
	Buildings	***Critical Community Facilities (CCF)***	***Population exposed to the hazard***
Very high	≥ 50% of buildings within community area are located within a mapped hazard area	≥ 25% of CCF within community area are located within a mapped hazard area	> 100 residents located within a mapped hazard area
High	21-49% of buildings within community area are located within a mapped hazard area	11-24% of CCF within community area are located within a mapped hazard area	11-100 residents located within a mapped hazard area
Moderate	11-20% of buildings within community area are located within a mapped hazard area	6-10% of CCF within community area are located within a mapped hazard area	2-10 residents located within a mapped hazard area
Low	2-10% of buildings within community area are located within a mapped hazard area	1-5% of CCF within community area are located within a mapped hazard area	1 resident located within a mapped hazard area
Very low	≤ 1% of buildings within community area are located within a mapped hazard area	No critical community facilities within the community area located within a mapped hazard area	No residents located within a mapped hazard area

3.1.3 RiskScape Analysis for Natural Hazard Exposure

Exposure analysis was completed using RiskScape, an open-source software with a flexible modelling engine for multi-hazard risk analysis (Paulik *et al*, 2022). RiskScape has a modular structure, integrating hazard, exposure (i.e., elements-at-risk), and consequence data in a workflow to quantify exposure, impact or risk from natural hazards.

RiskScape software (Version 1.8.0) was configured to identify *elements-at-risk* within the mapped hazard extent areas, then apply a binary exposure function (i.e., 1 = exposed to natural hazard; 0 = not exposed to natural hazard) to enumerate their exposure to natural hazards. The process to analyse and report natural hazard exposure in Otago is conceptually represented in Equation 3.1.

$$\mathbf{H_{exp}} = \begin{cases} \mathbf{1}, & \boldsymbol{Hazard\ Present} \\ \mathbf{0}, & \boldsymbol{Hazard\ Not\ Present} \end{cases} \quad \textbf{(1)}$$

The analysis process is summarised in Figure 3.1, and detailed in Appendix E which includes commentary on the natural hazards, statistical area and elements at risk input data, RiskScape model development, and analysis and reporting workflows.

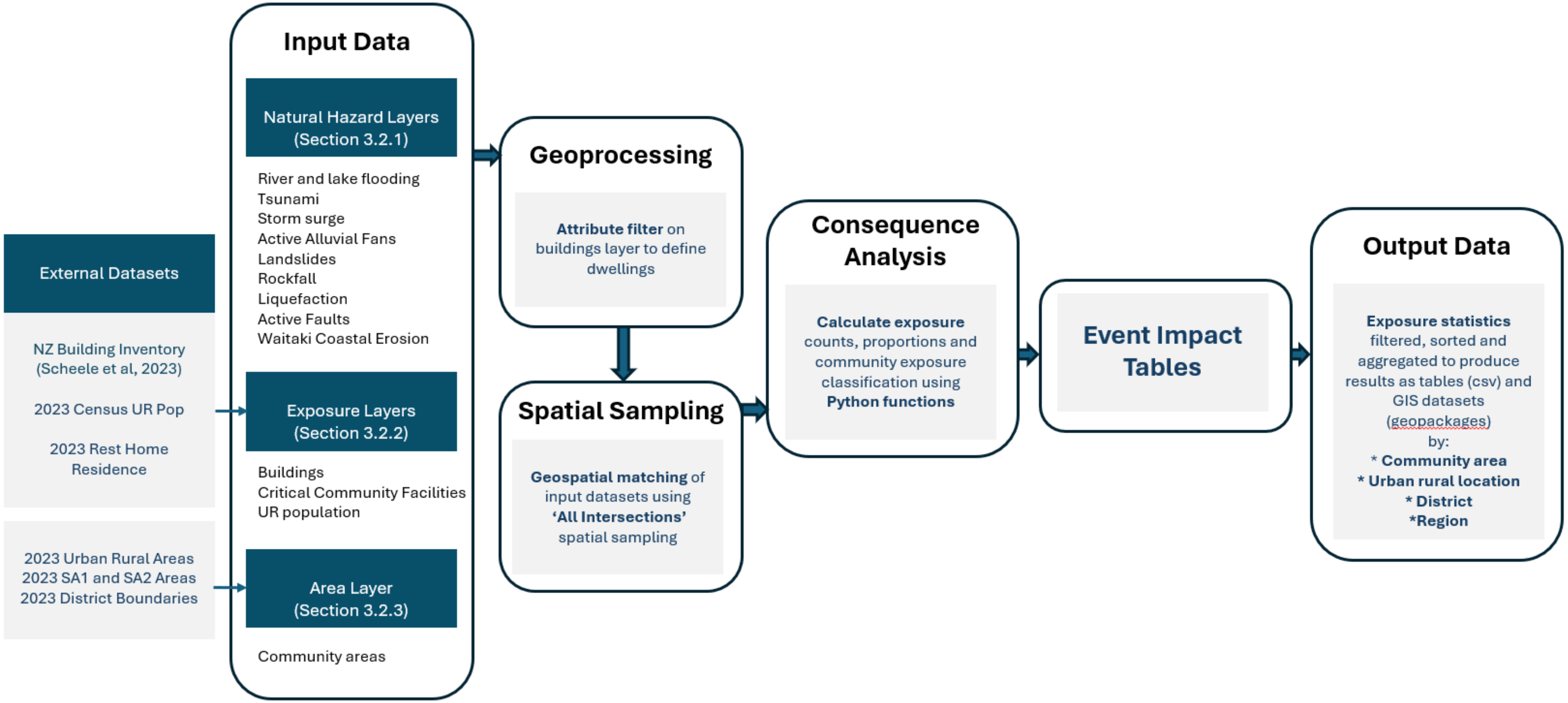

Figure 3.1: Generalised RiskScape model pipeline for the exposure analysis.

3.1.4 Aggregation and Reporting

Calculated exposure metrics for individual 'community areas' are then aggregated to give totals for each urban area and settlement, district, and the region as a whole. Table 3.3 summarises the exposure outputs reported for each geographic scale.

Where natural hazard exposure findings are not included in this technical report (e.g. exposure measures for individual community areas), these can be viewed through the online data viewer accessible at orc.govt.nz/naturalhazardexposure.

Table 3.3: Summary of exposure reporting outputs for each hazard type, where cells coloured green are outputs generated from this study.

Exposure reporting output	***Geographic area***			
	Community area (n= 351)	***Urban area or rural settlement (n = 54)***	***District***	***Region***
Exposure measures for usually resident population, buildings, dwellings and critical community facilities in each community area (measures listed in Table 3.1)	Online data viewer			
Aggregated exposure measures for usually resident population, buildings, dwellings and critical community facilities		Section 5 (e.g. Table 5.5)	Appendix D, Tables 9.4-9.8	Table 5.1
Exposure level classification for each community area (using the classification scheme in Table 3.2)	Online data viewer			
Numerical breakdown of the exposure level classifications for the community areas within a larger area		Section 5 (e.g. Table 5.5)	Appendix D, Tables 9.4-9.8	Table 5.1
A 'Top 10' table of community areas, ordered by population exposure	Table 5.2			
A 'Top 10' table of urban areas or rural settlements, ordered by population exposure		Section 5 (e.g. Table 5.5)		

3.2 Input Data

3.2.1 Natural Hazard Mapping

The natural hazards considered in this exposure analysis are those where ORC holds existing spatial mapping datasets with regional or district-wide coverage. The mapped natural hazard extents can be considered as an overlay or mask indicating locations which may be exposed to those natural hazards processes.

The natural hazard mapping layers used in this analysis are listed and described in Table 3.4. Mapping for each of these hazard types are shown in Appendix A as Figures 9.1-9.9.

The key limitations associated with the use of these natural hazards datasets for exposure analysis are summarised in Section 4.

Table 3.4: Natural hazards mapping layers used in this natural hazards exposure and risk analysis.

Hazard Type	***Hazard Mapping Dataset***	***Data coverage***	***Description***	***Reference for mapping dataset***	***Considers climate change or sea level rise***
Flooding	River, alluvial fan and lake flooding	Otago region	A dataset representing flood-prone areas, compiled for this study by merging a number of existing flood hazard mapping datasets (e.g. river floodplain, active floodwater-dominated alluvial fan streams, coastal streams). Most mapping is based on observations of historical flooding, and interpretation from aerial imagery and topographic datasets (e.g. LINZ Topo50 mapping or LiDAR). This mapping dataset does not include pluvial flooding (surface flooding from rainfall runoff where stormwater systems are overwhelmed).	Compilation of data from various sources (e.g. those described in ORC (1999a, b, c, 2002, 2014) and Grindley *et al* (2009)	No
Seismic	Active faults	Otago region	Mapped active faults, generally based on regional geologic mapping and air photo interpretation. For this study, active fault traces have been buffered by ±250m to create polygon features representing the area in near proximity to an active fault structure. 'Active' faults are those which have undergone at least one ground-deforming rupture within the last 125,000 years, or at least two ground-deforming ruptures within the last 500,000 years (Barrell, 2021).	Barrell (2016, 2019, 2021)	n/a
	Liquefaction susceptibility	Otago region	Mapping of areas which are potentially subject to liquefaction hazards, based on regional-scale geologic mapping (QMAP), and interpretation from aerial imagery, LiDAR topography, and borehole information. Equivalent to a basic desktop assessment as defined in the MBIE/MfE (2017) guidance.	Barrell *et al* (2014), Barrell (2019)	n/a

Hazard Type	***Hazard Mapping Dataset***	***Data coverage***	***Description***	***Reference for mapping dataset***	***Considers climate change or sea level rise***
Slope Stability	Landslide	Otago region	Mapping of interpreted locations of past landslide movements, generally based on interpretation from aerial imagery. This dataset does not represent landslide susceptibility (i.e. slopes which may fail in future), or areas which may be impacted by the runout of landslide debris, and predates the national landslide planning guidance (de Vilder *et al*, 2024).	Compiled from various sources, including; Barrell *et al* (2017), Forsyth (2001), Turnbull (2000), Turnbull and Allibone (2003)	No
	Rockfall	Otago region (excludes catchments devoid of buildings or roads, or with only very sparsely distributed buildings).	Rockfall 'awareness areas' which may be susceptible to rockfall. Developed based on RAMMS modelling from source areas defined by slope-angle analysis.	Easterbrook-Clarke *et al* (2022)	No
	Alluvial fan (debris inundation)	Otago region	Mapped alluvial fan surfaces which have been classed as 'active', and as either 'debris-dominated' or 'composite' (fans may be subject to a combination of both debris flow and floodwater flow processes). Active 'floodwater-dominated' alluvial fans were mapped and included in the original mapping dataset (Grindley *et al*, 2009), these have been included within the flood hazard layer compiled for this study.	Grindley *et al* (2009)	No

Hazard Type	***Hazard Mapping Dataset***	***Data coverage***	***Description***	***Reference for mapping dataset***	***Considers climate change or sea level rise***
Coastal	Coastal inundation and sea level impacts	Otago region	Modelled extents of potential inundation due to extreme sea level events with return periods of up to 500-year ARI.	Lane *et al* (2008)	Yes. Sea level rise scenarios of 0.3 and 0.5 m considered. These scenarios could be reached in approximately 2065 and 2095 under SSP2-4.5 (MfE, 2022).
	Coastal erosion	Waitaki District	Modelled future shoreline position with a 5% probability of erosion extending up to or landward of this line over the 100-year outlook period. Data converted to a polygon feature by buffering coastwards from the mapped coastal hazard zone (CHZ) line feature.	Bosserelle *et al* (2019)	Yes, up to an upper bound of 1.3 m sea level rise by 2115.
	Tsunami	Otago region	Numerical modelling findings showing the maximum area affected by a modelled tsunami from near and far-field sources, for events up to a 500-year ARI. There is no data available for lake tsunami or seiche.	Lane *et al* (2007)	Yes. Sea level rise scenarios of 0.3 and 0.5 m considered. These scenarios could be reached in approximately 2065 and 2095 under SSP2-4.5 (MfE, 2022).

3.2.2 Elements at Risk

Elements at risk are those which are exposed to the potential impacts of natural hazards events. The three "elements at risk" datasets used in this analysis represent aspects of the 'human' and 'built environment' domains defined by MfE (2020);

- Population
- Buildings
- Critical community facilities (CCF).

The development of these datasets is summarised below and further detailed in Appendix E. These elements align with the approach to assessing hazard consequences in the proposed Otago Regional Policy Statement 2021 (pORPS, ORC 2021), and were selected for use in this analysis because they are repeatable measures which can be used to provide an indication of the magnitude of exposure, and therefore of the relative impact of potential natural hazard events.

The three elements at risk selected for this analysis are considered sufficient to provide a broad regional overview, at a screening level, to identify the population, assets and locations exposed to natural hazards.

The proposed Otago Regional Policy Statement 2021 also includes lifelines infrastructure and social/cultural buildings in the approach to assessing hazard consequences, however these are not considered in this iteration of exposure analysis. Lifelines infrastructure (e.g. transport, communications and energy networks) are not included to avoid overlap or duplication with Emergency Management Otago's lifelines projects (e.g. Toa Consulting, 2024), and instead to complement any existing or future CDEM work in this area. The social/cultural buildings element is also not considered in the assessment, as at the time of writing no consistent and comprehensive dataset compiling all social/cultural buildings in Otago was available.

3.2.2.1 POPULATION

The usually resident population estimated to be exposed to a hazard is a primary indicator of social/community disruption in the event of hazard occurrence. NZ census 2023 usually resident population count data for all SA1 and SA2 units in the region was acquired from Statistics NZ (Stats NZ, 2025).

In order to provide an estimate of the spatial distribution of population in each statistical area, a population model was developed to estimate the distribution of residents within the buildings present. This is a refinement over simpler approaches such as assuming the population is evenly distributed within all buildings present within the statistical area, i.e. estimation based on a 'mean population per building' rate.

The model was based on the usually resident population count data for all SA1 and SA2 units, and identification of building types likely to represent dwellings. Model refinements were required to address limitations in accurately representing populations present in rest home dwellings, which contain a large population residing in one facility, and would not be well-represented in estimates based only on a 'population per dwelling' approach.

Information on rest home bed counts and occupancy is available for facilities in Otago via the Ministry of Health (Manatū Hauora) and Aged Residential Care websites (MoH, 2023; ARC, 2024). This information has been used to identify the spatial location for rest homes in Otago and make an estimate of their occupancy, which is then integrated with estimates for population within all other dwelling types. This estimation process is detailed in Appendix E.

3.2.2.2 BUILDINGS

The building inventory dataset (polygon geometry) was provided by GNS Science (Scheele *et al*, 2023). The dataset was developed using the latest (2024) LINZ NZ Building Outline and Primary Parcels datasets, in combination with property data acquired from Corelogic.

The dataset maps the outlines of all buildings larger than or equal to 10 square metres in size. The dataset will not include any buildings constructed since the date of its compilation in 2024, however this is not expected to cause any significant changes to the analysis findings.

In addition to dwellings, the dataset also includes other structures such as commercial buildings, garages, sheds and farm outbuildings. The building inventory layer was used to identify building types which represent a main place of residence for the usually resident population (i.e. where they sleep and generally live); buildings with a 'use category' field attribute of 'residential dwelling', 'lifestyle' and 'rest home' categories are chosen to represent dwellings.

Further building categorisation was undertaken for rural locations, where many buildings likely to be dwellings were initially assigned an 'unknown' use category attribute within the building inventory. A manual analysis process was carried out to identify and refine building use categorization for those buildings based on specific criteria developed to distinguish general rural farm type buildings (sheds, barns, garages, storage etc.) from those that could be considered dwellings. A new use category attribute ('farm/rural dwelling') was then created to identify those dwellings. This categorization process is detailed in Appendix E.

3.2.2.3 CRITICAL COMMUNITY FACILITIES

Critical Community Facilities (CCF) provide a direct measure of medical and emergency services, and disaster coordination/operations centres exposed to a hazard. They are an important indicator of social/community disruption in case of a hazard event where CCF and associated services are significantly affected or not available.

Critical community facilities (CCF) are defined as facilities which have a post-disaster function (ORC, 2021). There are a total of 90 critical community facilities identified in the region and used in this analysis (listed in Appendix C), these are;

- Medical facilities (hospitals or ambulance stations).
- Emergency service facilities (fire and police stations).
- Emergency Coordination Centre (ECC) and Emergency Operations Centres (EOC).

The Critical Community Facilities dataset (dated 2022) was acquired from Emergency Management Otago as a point geometry GIS feature layer with locations identified as points on or close to the relevant site of interest. To ensure all CCF building locations were included partly or fully within polygon boundaries for location units and natural hazard mapped layer extents, the point dataset was converted into polygon geometry. This was done by cross referencing the provided point locations with the latest available imagery (e.g. Google Earth and Google Street View), and then using the NZ Building Inventory dataset (set out in Section 3.2.2) to determine the outline extents of those building locations.

Emergency Coordination Centre (ECC) and Emergency Operations Centres (EOC) were not identified in the original point dataset of Critical Community Facilities, these were subsequently included based on location information provided by Emergency Management Otago.

As some facilities are made up of multiple buildings, the dataset attributes were modified to represent all buildings within a single facility as a single occurrence, to ensure all facilities are equally weighted in analysis.

3.2.3 Geographic Units

3.2.3.1 STATISTICAL AREAS

Statistical Area 1 (SA1) and Statistical Area 2 (SA2) geographic areas classified by Statistics New Zealand are used to give a consistent spatial division over the region for this natural hazards exposure analysis. The use of defined geographic units provides a systematic approach to dividing the region into smaller sub-areas with comparable population sizes.

The geographic resolution of this exposure analysis is a ‘community area’, defined using statistical units defined by Statistics New Zealand. These are intended to represent “a ‘community of place’ where people interact together socially and economically” (Stats NZ, 2022).

The hierarchy of statistical units developed by Statistics New Zealand (Stats NZ, 2022) is described in Appendix B. The boundaries of these units align and can be aggregated into larger contiguous units. For example, SA1’s are aggregated into SA2’s, and SA2’s aggregate to align with urban area/settlement, territorial authority and regional council boundaries.

For this analysis, the region is assessed as a series of 351 geographic units (Appendix B). These geographic units are SA2’s for urban areas where they are equivalent to suburbs, for rural settlements are either SA1 or SA2’s, and for areas outside of urban areas and rural settlements are SA1’s. For this analysis, these geographic units are referred to as ‘community areas’ and are the relevant spatial scale to describe a ‘community’. The finer spatial resolution represented by Stats NZ meshblock units is not used in this analysis.

3.2.3.2 URBAN RURAL GEOGRAPHY

Statistics NZ define the boundaries of urban areas and rural settlements in the region as distinct geographical units, which form the 'urban rural' (UR) geography dataset (Stats NZ, 2022). A total of 54 localities in the Otago region are identified as being either an urban area or rural settlement (Appendix B). The urban area and rural settlement geographies are formed by one or more SA1 or SA2 areas.

There are 14 localities in the region identified as urban areas with a population of ≥1,000, and an additional 40 rural settlements (Appendix B). Within these urban areas and rural settlements, SA2s have been used to provide a subdivision into smaller community-scale units. Rural areas outside of urban areas and rural settlements are classed as 'rural other' in the urban rural (UR) dataset. For these areas, SA1’s have been used to provide a sub-division into smaller geographic units.

4 Limitations

The most significant constraint on completion of a regional-scale natural hazards exposure assessment is the availability and consistency of data for natural hazards and elements at risk. This section presents and discusses the key limitations in this natural hazards exposure analysis.

Despite these limitations, the analysis is sufficient to provide a first-pass measure of the order of magnitude of potential natural hazards exposure across the Otago region.

4.1 Input Data

4.1.1 Natural Hazards Mapping

The natural hazards mapping data used in this analysis is the best natural hazards information with region-wide coverage currently available, however some inconsistencies are identified and a number of key limitations are noted, for example;

- Some data is derived from modelling and represents a specific likelihood event (e.g. coastal inundation and tsunami hazard (Lane *et al* 2007, 2008) but others are developed based on observation of historical events and/or geomorphic interpretation and do not have an associated likelihood (e.g. river and lake flooding, alluvial fan (Grindley *et al*, 2009), or landslide hazards (e.g. Barrell *et al*, 2017).

- Some datasets include consideration of climate change or sea level rise (e.g. coastal inundation, tsunami and coastal erosion (Lane *et al* 2007, 2008; Bosserelle *et al*, 2019), but climate change effects are not accounted for in other datasets such as flood hazard mapping or landslides (e.g. Barrell *et al*, 2017).

- This exposure analysis has used only ORC's regional or district-scale hazards mapping datasets. More detailed natural hazard information is available in many locations (e.g. local-scale flood hazard modelling or geotechnical investigations) but was not used for this initial analysis to maintain consistency of data resolution across the full region.

- Most of the hazards mapping datasets identify mapped areas susceptible to potential future impact from that hazard type, but a key exception is the landslide dataset (e.g. Barrell *et al*, 2017; Turnbull, 2000) which represents only mapping of existing landslide features, but not areas of potential future landslide susceptibility (i.e. slopes which have not yet failed), or areas which may be impacted by the runout of landslide debris. Additionally, some of the mapped landslide features included in the analysis are currently inactive (i.e. not active since prehistoric times) and therefore not necessarily posing a high threat.

- The rockfall awareness areas used in exposure analysis (Easterbrook-Clarke *et al*, 2022) were developed for a domain which excluded hydrologic catchments with no roads present and where buildings were absent or only sparsely distributed, largely in the mountainous parts of the Queenstown Lakes District (see Figure 9.6, Appendix A). The rockfall hazard mapping coverage therefore does not have complete region-wide coverage, but the mapping dataset will include the large majority of the elements at risk (population and buildings) considered in this exposure analysis.

- The active faults used in analysis should be regarded as a minimum representation of the active faults of the region, as earthquake rupture can also occur on as-yet undetected active faults (Barrell, 2021). The mapped active fault traces are generalised and their locations are therefore subject to uncertainty. Barrell (2021) notes that mapped locations are located within ±100 metres at best, and ±250 metres as a general rule.

- Several hazard mapping datasets have been compiled from a range of composite sources or using differing methodologies, leading to variation in the precision and quality of information within a specific mapping dataset;
    - The composite flood hazard layer used in this analysis includes both mapping of flood prone areas (based in part on flood event observations (e.g. ORC, 2025)) and mapping of floodwater-dominated alluvial fans (based on desktop analysis from aerial imagery and topographic interpretation (Grindley *et al*, 2009)). This flood hazard dataset does not include pluvial flooding,[3] meaning that some known flood-prone areas such as the South Dunedin plain are not identified as exposed to flooding hazard in this analysis. For flood hazards in areas of the ORC's flood protection schemes, the population and buildings located within the 'protected' areas are considered to be potentially exposed to the hazard and are included within exposure analysis. This is because these areas could still be exposed to flooding in the case of a super-design flood event or failure of flood protection infrastructure.

    - The landslide dataset used in this analysis is based on regional-scale mapping of landslide features (e.g. QMAP 1:2,500,000 series landslide layers compiled at a 1:50,000 scale), but for the coastal sector of the Dunedin City District the dataset includes higher resolution mapping compiled at a scale of 1:10,000 or better (Barrell *et al*, 2017).

    - The active fault traces included in analysis range in certainty from 'definite' to 'potentially active', and these include features where it is not possible to rule out other origins (e.g. formation due to erosion), or faults which require further positive information be treated as active faults (Barrell, 2021).

4.1.2 Elements at Risk

The key limitations of the elements at risk are associated with the development of the population and building datasets used in analysis

4.1.2.1 POPULATION

- "Usually resident" population is based on values from the 2023 census, so will not account for any changes in population since that time.

- The spatial distribution of the population was estimated by modelling population allocation into building types likely to represent dwellings. This is therefore an approximation rather than a measurement of population in each dwelling, and influenced by uncertainties in the building categorization dataset.

- The use of 'usually resident' population census values does not represent the spatial or temporal distribution of other populations such as transient tourist or seasonal worker

[3] A flood event caused by rainfall where the rainfall exceeds the capacity of the ground, drainage systems, or swales to absorb or drain the rainfall. This can be independent of an overflowing water body from rivers.

populations, so these are not included in estimates of population exposure. Similarly, a significant daytime population could be present in workplace locations during working hours, but is not included in estimates of population exposure based on usually resident population.

4.1.2.2 BUILDINGS

- In rural areas of Otago, the classification of building use category was less comprehensive than in urban areas, and further classification was required to identify and categorise rural dwellings (Scheele *et al*, 2023). Although an improvement to the dataset, this further classification is still only an approximation, and uncertainties also have a flow-on effect as this building categorisation is then used as an input in estimation of population.

- The building outline dataset used in analysis was compiled in 2024, so will not account for any buildings constructed (or removed) since that time. However, this is not expected to cause any significant drawback to the analysis as the rate of new building construction over this time is not considered to be significant compared to the relative quantity of pre-2024 buildings in the dataset.

4.2 Methodological Limitations

4.2.1 Exposure Analysis

- A key limitation in exposure analysis is the assumption that all buildings and population exposed within a mapped hazards extent may come into contact with the natural hazard process, which could then cause an adverse impact to those elements. This is an approximation only, and a conservative approach as not every resident or building may be significantly affected, for example in the case of minor 'nuisance' flooding which does not reach the floor level of a building.

- The 'exposure level' classification for community areas (Table 3.2) uses a first-past-the-post approach rather than a weighted scoring across the three elements at risk. In some cases, the proportion-based classification criteria (buildings and critical community facilities) identify a high proportion of the element but of a relatively low total count. For example, one community area[4] in a remote area has a usually resident population of four residents and only 10 buildings present, but is classed as having 'high' exposure because >50% of those buildings are located in the mapped alluvial fan hazard area. The 'exposure level' classification is therefore considered a useful indicator of overall exposure level, but consideration of the individual exposure components will provide a fuller understanding of the exposure levels and their drivers.

[4] The 'Hunter River' community area at the head of Lake Hawea.

5 Results

5.1 Natural Hazard Exposure

5.1.1 Introduction

Natural hazards exposure analysis results are presented in tabular form in this report section and can be viewed spatially through a digital data portal which complements this technical report. The viewer presents hazards mapping layers, elements at risk information, and all natural hazards exposure outputs. The exposure data portal can be accessed at orc.govt.nz/naturalhazardexposure and copies of output datasets in spreadsheet or GIS format can be provided on request.

At a regional level, Table 5.1 presents a summary of natural hazards exposure, showing aggregated totals for each hazard type. Similar results tables with these exposure outputs tabulated for each district are included as Tables 9.4-9.8 in Appendix D. Tables 5.2 and 5.3 provide a summary of the top 10 urban areas/settlements and community areas in the region exposed to each hazard type.

For each hazard type, exposure analysis results are summarised in a series of two tables;

- A summary table showing the estimated count and percentage of those elements within each district potentially exposed to impact from the hazard (e.g. Table 5.4).
- A 'Top 10' table listing the urban areas and settlements with the greatest hazard exposure, ranked by the usual resident population exposed to the hazard, and presents the exposure totals aggregated for the urban areas or settlement (e.g. Table 5.5).

The count of critical community facilities exposed to each hazard type are included in Tables 5.4-5.21, these exposed facilities are identified in Table 9.9, Appendix D.

For any urban area/settlement or community area, where exposure analysis results are not presented within this technical report, they can be viewed through the exposure data portal.

5.1.2 Regional and District Summary

Regional-level natural hazards exposure outputs are summarised in Table 16, which shows a comparison between the elements exposed to the range of natural hazard types assessed.

Exposure analysis demonstrates that the two hazard types in the Otago region with the greatest populations and buildings located within hazard-prone areas are river and lake flooding and liquefaction (Table 16). There is also a notable spatial overlap between the geographic extents of these two hazard types, because flood-prone floodplain areas typically comprise geologically-recent sediment deposits which may also be susceptible to liquefaction. Although liquefaction hazard has the highest exposure in terms of population, this hazard does not necessarily pose the highest risk to the region as the likelihood of occurrence for a major earthquake triggering liquefaction is lower than other hazard types such as flooding.

In comparison, hazard types with a more localised spatial occurrence, or in locations less appealing for residential development, have a significantly lower exposure level. For example, potential coastal inundation impacts are limited to the immediate coastal margins, and rockfall impacts are limited to the immediate downslope extents below steep source areas.

Table 5.1: Natural hazards exposure summary for the Otago Region, showing the estimated count and percentage of those elements within Otago potentially exposed to impact from the named natural hazard types.

Hazard type	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in region
	Count	Percent of population in region	Count (all buildings)	Percent of total buildings in region	Count (Dwellings)	Percent of total dwellings in region	Count	Percent of total CCF in region	Very Low	Low	Moderate	High	Very High	
River and lake flooding	38,778	16.1	33,898	16.1	12,776	14.4	23	25.6	121	26	45	99	60	351
Liquefaction	46,047	19.1	43,029	20.4	17,459	19.7	37	41.1	142	18	45	68	78	351
Active Faults	21,949	9.1	20,096	9.5	8,371	9.4	10	11.1	203	19	21	68	40	351
Landslide	8,038	3.3	6,592	3.1	2,844	3.2	3	3.3	225	14	51	41	20	351
Alluvial fan	5,473	2.3	5,904	2.8	1,996	2.3	3	3.3	272	10	18	38	13	351
Rockfall	1,234	0.5	1,056	0.5	377	0.4	0	0	290	14	29	14	4	351
Tsunami	504	0.2	1,130	0.5	266	0.3	0	0	327	4	7	12	1	351
Storm surge	504	0.2	1,122	0.5	230	0.3	0	0	325	7	8	10	1	351
Coastal Erosion (Waitaki)	37	0	111	0.1	19	0.0	0	0	346	1	3	1	0	351

Table 5.2: Natural hazards exposure summary for the Otago Region, showing the 'Top 10' urban areas or rural settlements with highest exposure for each hazard type, identified and ordered by the estimated population exposed to the hazard within that urban area/settlement. The population exposed within each urban area/settlement is indicated by the cell shading (see legend). Coastal erosion hazard is not included in the table, as there is insufficient data to provide a region-wide comparison across the full Otago coastline.

Hazard type							
River and lake flooding	**Liquefaction**	**Active Faults**	**Landslide**	**Alluvial fan**	**Rockfall**	**Tsunami**	**Storm surge**
Mosgiel	Dunedin	Dunedin	Dunedin	Queenstown	Queenstown	Pounawea	Dunedin
Dunedin	Mosgiel	Mosgiel	Wanaka	Dunedin	Dunedin	Taieri Mouth	Waikouaiti
Oamaru	Wanaka	Alexandra	Warrington	Wanaka	Arrowtown	Purakaunui	Purakaunui
Queenstown	Queenstown	Wanaka	Queenstown	Roxburgh	Wanaka	Brighton	Pounawea
Balclutha	Milton	Lake Hawea	Mosgiel	Palmerston	Roxburgh	Waikouaiti	Taieri Mouth
Outram	Balclutha	Roxburgh	Moeraki	Waikouaiti	Aramoana	Karitane	Waitati-Doctors Point
Milton	Outram	Kaitangata	Roxburgh	Glenorchy	Purakaunui	Waitati-Doctors Point	Brighton
Luggate	Kingston	Waihola	Brighton	Arrowtown	Lake Roxburgh	Kaka Point	Karitane
Glenorchy	Glenorchy	Allanton	Karitane	Kingston	Oamaru	Kaitangata	Kakanui
Waihola	Brighton	Queenstown	Waitati-Doctors Point	Harington Point	Moeraki	Kakanui	Moeraki

Legend
Population exposed
>5,000
1000-5000
500-1000
100-500
20-100
≤20

Table 5.3: Natural hazards exposure summary for the Otago Region, showing the 'Top 10' community areas with highest exposure for each hazard type, identified and ordered by the estimated population exposed to the hazard within that community area. Where a community area forms part of a larger urban area/settlements, that larger area is named within parentheses. Community areas outside of urban area/settlements are noted as 'rural'. The population exposed and the exposure level classification for each community area are indicated by the cell shading and text formatting, respectively (see legend). Coastal erosion hazard is not included in the table, as there is insufficient data to provide a region-wide comparison across the full Otago coastline.

Hazard type							
River and lake flooding	**Liquefaction**	**Active Faults**	**Landslide**	**Alluvial fan**	**Rockfall**	**Tsunami**	**Storm surge**
Mosgiel East (Mosgiel)	St Kilda South (Dunedin)	East Taieri (Mosgiel)	Fernhill (Dunedin)	Warren Park (Queenstown)	Warren Park (Queenstown)	Pounawea	*Waikouaiti*
Gardens (Dunedin)	Mosgiel Central (Mosgiel)	Green Island (Dunedin)	Abbotsford (Dunedin)	Roseneath-Sawyers Bay (Dunedin)	Sunshine Bay-Fernhill (Queenstown)	*Taieri Mouth*	*Pūrākaunui*
Seddon Park (Mosgiel)	Seddon Park (Mosgiel)	Caversham (Dunedin)	Dunedin Central (Dunedin)	Wānaka West (Wanaka)	Arthurs Point (Queenstown)	*Pūrākaunui*	Pounawea
Mosgiel Central (Mosgiel)	St Kilda North (Dunedin)	Wakari (Dunedin)	Roslyn (Dunedin)	Frankton (Queenstown)	*Arrowtown*	*Brighton*	*Andersons Bay (Dunedin)*
Bush Road (Mosgiel)	South Dunedin (Dunedin)	Seddon Park (Mosgiel)	Warrington	Roxburgh	*Glenleith (Dunedin)*	*Owaka Valley East (Clutha rural)*	*Taieri Mouth*
Campus South (Dunedin)	Bush Road (Mosgiel)	Albert Town (Wanaka)	Brockville (Dunedin)	Sunshine Bay-Fernhill (Queenstown)	*Maori Hill (Dunedin)*	*Glenledi-Toko Mouth (Clutha rural)*	*Waverley (Dunedin)*
Oamaru North Milner Park (Oamaru)	Milton	Alexandra South (Alexandra)	Wānaka Central (Wanaka)	Palmerston	*Gibbston (Queenstown rural)*	*Waikouaiti*	*Waitati-Doctors Point*
Jacks Point (Queenstown)	Campus South (Dunedin)	Roslyn (Dunedin)	Albert Town (Wanaka)	Queenstown Central (Queenstown)	*Frankton (Queenstown)*	*Purakaunui (Clutha rural)*	*Glenledi-Toko Mouth (Clutha rural)*
Balclutha South (Balclutha)	Albert Town (Wanaka)	Wingatui (Mosgiel)	Wānaka West (Wanaka)	Broad Bay-Portobello (Dunedin)	*Otago Harbour Deborah Bay To Aramoana (Dunedin rural)*	*Karitāne*	*Brighton*
Campus North (Dunedin)	Jacks Point (Queenstown)	Lake Hāwea	Kaikorai-Bradford (Dunedin)	Waverley (Dunedin)	*St Clair (Dunedin)*	*Waitati-Doctors Point*	*Karitāne*

Legend	
Population exposed	**Exposure Class**
>2,500	Very High (regular)
1000-2500	*High (italics)*
500-1000	
100-500	
20-100	
≤20	

5.1.3 River and Lake Flood Hazard

There are a total of approximately 38,000 people and 34,000 buildings, including >12,000 dwellings, within the Otago region located in areas identified as potentially prone to river or lake flooding (Table 5.4). The majority of the population (72%) and buildings (58%) exposed are those located within the Dunedin City district, however all districts include a total of ≥1400 people and >500 dwellings exposed to the hazard.

A total of 23 critical community facilities in the region are located in flood-prone areas, this includes 11 fire stations, 6 police stations, 4 ambulance facilities and 1 hospital complex, and one Emergency Operations Centre (Table 9.9).

A 'top-10' list of the urban areas or rural settlements most exposed to flooding hazards (in terms of estimated population numbers) are shown in Table 5.5. This table shows the ten urban areas or rural settlements in the region assessed as having the greatest population exposed to flooding hazards.

In general, the flood hazard areas with the highest exposure are those which have been the focus of more detailed flood hazard assessments or the construction of engineered flood protection infrastructure (i.e. the ORC's Leith, Lower Taieri and Lower Clutha Flood Protection Schemes). For example, urban areas or rural settlements in the top-10 flooding exposure list (Table 5.5) include Dunedin City, the settlements of the Taieri Plain (Mosgiel, Outram, Waihola), Balclutha, Milton, Queenstown and Glenorchy.

Flood hazard exposure for each 'community area' has been classed using the criteria in Table 3.2, with about 159 (45%) of the 351 community areas in the region classified with a 'high' or 'very high' exposure to flood hazards (Table 5.4).

Table 5.4: Flood hazard exposure summary for the Otago region, showing the estimated count and percentage of those elements within each district potentially exposed to impact from flooding events.

District	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in district
	Count	Percent of population in district	Count (all buildings)	Percent of total buildings in district	Count (Dwellings)	Percent of total dwellings in district	Count	Percent of total CCF in district	Very Low	Low	Mod.	High	Very High	
Dunedin City	27,969	21.7	19,683	21.9	8,666	19.2	10	33.3	47	1	7	23	39	117
Clutha	3,754	20.5	5,593	18.7	1,276	21.2	10	45.5	18	8	5	23	10	64
Queenstown-Lakes	2,883	6	3,161	8.7	1,387	7.2	1	7.7	29	8	14	14	4	69
Waitaki	2,707	12.5	2,870	11.2	924	11.3	0	0.0	21	5	9	10	4	49
Central Otago	1,466	6	2,591	9	523	5.2	2	11.8	6	4	10	29	3	52
Otago Total	38,778		33,898		12,776		23		121	26	45	99	60	351

Table 5.5: Flood hazard exposure summary for the Top 10 urban areas or rural settlements in the Otago region, identified and ordered by the estimated population exposed to the hazard within that urban area/settlement.

Location	District	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in location
		Count	Percent of population in location	Count (all buildings)	Percent of total buildings in location	Count (Dwellings)	Percent of total dwellings in location	Count	Percent of total CCF in location	Very Low	Low	Mod.	High	Very High	
Mosgiel	Dunedin City	12,530	85.9	8,765	87.1	4,993	86.6	3	100.0	0	0	0	0	6	6
Dunedin	Dunedin City	12,078	12.0	5,560	9.4	2,635	7.7	5	25.0	22	0	1	11	17	51
Oamaru	Waitaki	1,989	14.5	1,466	13.9	784	14.0	0	0.0	6	0	0	0	2	8
Queenstown	Queenstown-Lakes	1,546	6.2	1,027	8.2	819	10.0	0	0.0	7	1	3	1	1	13
Balclutha	Clutha	1,105	25.4	1,104	34.5	421	24.5	3	75.0	0	0	0	1	1	2
Outram	Dunedin City	912	100.0	734	100.0	356	100.0	1	100.0	0	0	0	0	1	1
Milton	Clutha	839	39.6	827	41.1	358	40.2	2	66.7	0	0	0	0	1	1
Luggate	Queenstown-Lakes	461	73.5	365	76.2	175	73.5	1	100.0	0	0	0	0	1	1
Glenorchy	Queenstown-Lakes	351	96.6	467	86.8	171	96.6	0	0.0	0	0	0	0	1	1
Waihola	Clutha	324	63.1	346	65.0	130	63.1	0	0.0	0	0	0	0	1	1

5.1.4 Alluvial Fan Hazard

There are a total of 5,400 people and 5,900 buildings, including about 2000 dwellings, within the Otago region located in areas identified as being prone to inundation or debris hazards from active alluvial fans (Table 5.6). This analysis includes active alluvial fan surfaces mapped as being ‘debris-dominated’ or ‘composite’ but excludes those solely characterised as ‘floodwater-dominated’ (these are included within analysis of flooding hazards). Composite fans are those where debris and floodwater processes are unable to be separated at the scale of mapping, or the fans may be subject to both processes.

A majority of the population (81%) and buildings (72%) exposed to these alluvial fan hazards are those located within either the Queenstown Lakes or Dunedin City districts, with lesser exposure in the Central Otago, Waitaki and Clutha districts.

A total of 3 critical community facilities in the region are located in active alluvial fan hazard areas; 2 police stations and 1 fire station (Table 9.9).

A top-10 list of the urban areas or rural settlements exposed to active alluvial fan hazards are shown in Table 5.7. This table shows the ten urban areas or rural settlements in the region assessed as having the greatest population exposed to active alluvial fan hazards.

Many of these alluvial fan locations have been the focus of previous alluvial fan hazards investigations by ORC or territorial authorities, in particular those at Queenstown (Brewery Creek and Reavers Lane), Wanaka (Stoney Creek and Waterfall Creek), Roxburgh (Reservoir Creek and other nearby catchments) and Glenorchy (Buckler Burn). The majority of the Buckler Burn alluvial fan is mapped as ‘floodwater-dominated’ so is included only within the flooding hazard analysis, the values for Glenorchy in Table 5.7 refer only to the portion of the Buckler Burn fan mapped as ‘debris dominated’.

For Dunedin city, the relatively high exposure is due to the number of ‘debris-dominated’ active alluvial fans located on the Otago Peninsula, such as those at Broad Bay, Portobello and Challis. For Waikouaiti, exposure is due to Post Office Creek and several other urban stream areas which are classed as ‘composite’ alluvial fans.

Active alluvial fan hazard exposure for each ‘community area’ has been classed using the criteria in Table 3.2, with 51 (~15%) of the 351 community areas in the region classified with a ‘high’ or ‘very high’ exposure to alluvial fan hazards (Table 5.6).

Table 5.6: Alluvial fan hazard exposure summary for the Otago region, showing the estimated count and percentage of those elements within each district potentially exposed to debris inundation impact.

District	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in district
	Count	Percent of population in district	Count (all buildings)	Percent of total buildings in district	Count (Dwellings)	Percent of total dwellings in district	Count	Percent of total CCF in district	Very Low	Low	Mod.	High	Very High	
Queenstown-Lakes	3,189	6.7	2,862	7.9	1,104	5.7	1	7.7	29	3	6	24	7	69
Dunedin City	1,294	1.0	1,436	1.6	530	1.2	1	3.3	103	3	4	3	4	117
Central Otago	734	3.0	1,063	3.7	256	2.6	0	0.0	34	3	3	11	1	52
Waitaki	238	1.1	451	1.8	102	1.3	1	12.5	46	0	2	0	1	49
Clutha	17	0.1	92	0.3	4	0.1	0	0.0	60	1	3	0	0	64
Otago Total	5,473		5,904		1,996		3		272	10	18	38	13	351

Table 5.7: Alluvial fan hazard exposure summary for the Top 10 urban areas or rural settlements in the Otago region, identified and ordered by the estimated population exposed to the hazard within that urban area/settlement.

Location	District	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in location
		Count	Percent of population in location	Count (all buildings)	Percent of total buildings in location	Count (Dwellings)	Percent of total dwellings in location	Count	Percent of total CCF in location	Very Low	Low	Mod.	High	Very High	
Queenstown	Queenstown-Lakes	2,085	8.3	1,214	9.7	521	6.4	1	16.7	5	0	1	2	5	13
Dunedin	Dunedin City	1,172	1.2	1,084	1.8	484	1.4	1	5.0	47	0	0	0	4	51
Wanaka	Queenstown-Lakes	624	5.2	559	5.6	392	6.3	0	0.0	5	0	0	0	1	6
Roxburgh	Central Otago	279	44.1	235	32.8	149	45.0	0	0.0	0	0	0	0	1	1
Palmerston	Waitaki	221	20.9	306	25.6	98	21.3	1	50.0	0	0	0	0	1	1
Waikouaiti	Dunedin City	51	4.0	85	6.1	25	4.0	0	0.0	0	0	0	1	0	1
Glenorchy	Queenstown-Lakes	25	6.8	37	6.9	12	6.8	0	0.0	0	0	0	1	0	1
Arrowtown	Queenstown-Lakes	19	0.7	17	0.8	9	0.7	0	0.0	0	0	0	1	0	1
Kingston	Queenstown-Lakes	15	3.7	16	3.3	8	3.7	0	0.0	0	0	0	1	0	1
Harington Point	Dunedin City	10	5.3	34	6.7	4	5.3	0	0.0	0	0	1	0	0	1

5.1.5 Active Fault Hazards

There are a total of about 22,000 people and 20,000 buildings, including 8,000 dwellings, within the Otago region located in areas identified as being located in proximity (within 250 metres) of active faults (Table 5.8). The majority of the population (63%) and buildings (51%) exposed to active fault hazards are those located within the Dunedin City district, with lesser exposure in the remaining districts.

A total of ten critical community facilities in the region are located in proximity to active faults; 3 police stations, 6 fire stations, and one Emergency Operations Centre (Table 9.9).

A top-10 list of the urban areas or rural settlements exposed to active fault hazards are shown in Table 5.9. This table shows the ten urban areas or rural settlements in the region assessed as having the greatest population located in near proximity to active faults.

The relatively high exposure in the Dunedin City district is due to the presence of the Kaikorai and Titri Faults, which run through Dunedin city and Mosgiel, respectively. Alexandra is intersected by several strands of the Galloway Fault zone, and both Wanaka and Lake Hawea by the Cardrona-Hawea Fault.

The locations of highest exposure are not necessarily at the highest risk for fault rupture hazards, as the exposure analysis does not account for the variation in ground-surface rupture recurrence interval for each fault, which ranges from <2000 years for the Akatore and Settlement Faults, to ≥50,000 years for others.

Active fault hazard exposure for each ‘community area’ has been classed using the criteria in Table 3.2, with 108 (~31%) of the 351 community areas in the region classified with a ‘high’ or ‘very high’ exposure to alluvial fan hazards (Table 5.8).

Table 5.8: Active fault hazard exposure summary for the Otago region, showing the estimated count and percentage of those elements within each district potentially exposed to impact from fault rupture.

District	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in district
	Count	Percent of population in district	Count (all buildings)	Percent of total buildings in district	Count (Dwellings)	Percent of total dwellings in district	Count	Percent of total CCF in district	Very Low	Low	Mod.	High	Very High	
Dunedin City	13,748	10.7	10,158	11.3	5,273	11.7	3	10.0	73	7	4	11	22	117
Central Otago	3,758	15.5	4,694	16.3	1,517	15.2	5	29.4	11	2	5	26	8	52
Queenstown-Lakes	2,172	4.5	1,891	5.2	899	4.7	1	7.7	51	3	4	8	3	69
Clutha	1,774	10.0	2,624	8.8	581	9.7	1	4.5	33	6	3	17	5	64
Waitaki	497	2.3	729	2.8	101	1.2	0	0.0	35	1	5	6	2	49
Otago Total	21,949		20,096		8,371		10	11.1	203	19	21	68	40	351

Table 5.9: Active fault hazard exposure summary for the Top 10 urban areas or rural settlements in the Otago region, identified and ordered by the estimated population exposed to the hazard within that urban area/settlement.

Location	District	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in location
		Count	Percent of population in location	Count (all buildings)	Percent of total buildings in location	Count (Dwellings)	Percent of total dwellings in location	Count	Percent of total CCF in location	Very Low	Low	Moderate	High	Very High	
Dunedin	Dunedin City	8,293	8.2	5,895	10.0	3,269	9.5	3	15.0	35	1	0	3	12	51
Mosgiel	Dunedin City	4,374	30.0	2,823	28.0	1,657	28.7	0	0.0	1	0	0	0	5	6
Alexandra	Central Otago	1,617	28.9	1,300	30.4	721	29.5	2	50.0	0	0	0	0	2	2
Wanaka	Queenstown-Lakes	1,042	8.7	828	8.3	426	6.8	0	0.0	3	0	0	2	1	6
Lake Hawea	Queenstown-Lakes	727	36.3	544	35.4	335	36.3	1	100.0	0	0	0	0	1	1
Roxburgh	Central Otago	586	92.6	628	87.7	307	92.7	2	100.0	0	0	0	0	1	1
Kaitangata	Clutha	573	69.0	574	63.6	238	69.0	0	0.0	0	0	0	0	1	1
Waihola	Clutha	329	64.1	370	69.5	132	64.1	0	0.0	0	0	0	0	1	1
Allanton	Dunedin City	235	68.2	220	70.7	90	68.2	0	0.0	0	0	0	0	1	1
Queenstown	Queenstown-Lakes	130	0.5	94	0.7	44	0.5	0	0.0	12	0	0	0	1	13

5.1.6 Liquefaction Hazard

There are a total of 46,000 people and 43,000 buildings, including >17,000 dwellings, within the Otago region located in areas identified as being potentially susceptible to liquefaction (Table 5.10). This analysis includes all areas mapped as having either a 'low to moderate' or 'moderate to high' susceptibility to liquefaction, as mapped in studies by Barrell *et al* (2014) and Barrell (2019). In the terminology of the MBIE/MfE guidance (2017), these are collectively classed as being locations where 'Liquefaction damage is possible'.

The majority of the population (66%) and buildings (56%) which are exposed to potential liquefaction hazard are those located within the Dunedin City District, however all districts include a total of >500 people and >1000 buildings exposed to liquefaction hazards.

A total of 35 critical community facilities in the region are located in liquefaction-prone areas, this includes 18 fire stations, 12 police stations, 4 ambulance stations and 1 hospital complex (Table 9.9).

A top-10 list of the urban areas or rural settlements exposed to liquefaction hazards are shown in Table 5.11. This table shows the ten urban areas or rural settlements in the region assessed as having the greatest population exposed to liquefaction hazards. About 50% of the population identified as being potentially susceptible to liquefaction are in either the Dunedin City urban area or Mosgiel, with sizeable (>1000) populations also exposed in Wanaka, Queenstown, Milton and Balclutha.

Liquefaction hazard exposure for each 'community area' has been classed using the criteria in Table 3.2, with about 42% (146) of the 351 community areas in the region classified with a 'high' or 'very high' exposure to liquefaction hazard (Table 5.10).

The assessment of liquefaction hazard exposure only demonstrates the locations where geological and groundwater conditions are such that liquefaction may occur, given sufficient earthquake shaking as a trigger event. Exposure analysis does not account for the spatial variability in the likelihood of a major earthquake shaking capable of triggering liquefaction, which is more likely to occur in the western parts of the region (Murashev and Davey, 2004).

Table 5.10: Liquefaction hazard exposure summary for the Otago region, showing the estimated count and percentage of those elements within each district potentially exposed to impact from liquefaction events.

District	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in district
	Count	Percent of population in district	Count (all buildings)	Percent of total buildings in district	Count (Dwellings)	Percent of total dwellings in district	Count	Percent of total CCF in district	Very Low	Low	Mod.	High	Very High	
Dunedin City	30,128	23.4	23,924	26.7	10,673	23.7	14	46.7	48	1	11	16	41	117
Queenstown-Lakes	8,870	18.6	8,059	22.2	4,350	22.5	4	30.8	25	6	8	17	13	69
Clutha	5,184	28.3	7,442	24.8	1,901	31.6	14	63.6	15	7	8	18	16	64
Waitaki	992	4.6	1,967	7.7	268	3.3	3	37.5	17	2	15	10	5	49
Central Otago	872	3.6	1,637	5.7	267	2.7	2	11.8	37	2	3	7	3	52
Otago Total	46,047		43,029		17,459		37		142	18	45	68	78	351

Table 5.11: Liquefaction hazard exposure summary for the Top 10 urban areas or rural settlements in the Otago region, identified and ordered by the estimated population exposed to the hazard within that urban area/settlement.

Location	District	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in location
		Count	Percent of population in location	Count (all buildings)	Percent of total buildings in location	Count (Dwellings)	Percent of total dwellings in location	Count	Percent of total CCF in location	Very Low	Low	Mod.	High	Very High	
Dunedin	Dunedin City	18,082	17.9	12,061	20.4	5,945	17.3	9	45	23	0	3	5	20	51
Mosgiel	Dunedin City	8,333	57.1	6,098	60.6	3,411	59.2	3	100	1	0	0	1	4	6
Wanaka	Queenstown-Lakes	4,357	36.6	3,879	39.1	2,291	36.8	2	67	1	0	1	0	4	6
Queenstown	Queenstown-Lakes	3,206	12.8	2,137	17.0	1,429	17.5	2	33	3	0	1	4	5	13
Milton	Clutha	1,994	94.0	1,854	92.2	837	94.0	3	100	0	0	0	0	1	1
Balclutha	Clutha	1,071	24.6	1,072	33.5	408	23.7	3	75	0	0	0	1	1	2
Outram	Dunedin City	909	99.7	733	99.9	355	99.7	1	100	0	0	0	0	1	1
Kingston	Queenstown-Lakes	393	100.0	479	99.8	216	100.0	0	0	0	0	0	0	1	1
Glenorchy	Queenstown-Lakes	363	100.0	502	93.3	177	100.0	0	0	0	0	0	0	1	1
Brighton	Dunedin City	317	22.0	311	22.8	135	22.0	0	0	0	0	0	0	1	1

5.1.7 Landslide Hazard

There are a total of 8,000 people and 6,500 buildings, including nearly 3,000 dwellings, within the Otago region located in areas identified as being located within mapped landslide features (Table 5.12). A large majority of the population (97%) and buildings (90%) exposed are those located within the Dunedin City or Queenstown Lakes districts.

A total of 2 critical community facilities in the region are located in mapped landslide features, this includes 1 fire station and 1 police station.

A top-10 list of the urban areas or rural settlements exposed to landslide hazards are shown in Table 5.13. This table shows the ten urban areas or rural settlements in the region assessed as having the greatest population being located within mapped landslide features.

Landslide feature exposure for each ‘community area’ has been classed using the criteria in Table 3.2, with 61 (~17%) of the 351 community areas in the region classified with a ‘high’ or ‘very high’ exposure to landslide features (Table 5.12).

It is important to note that this analysis is based only on mapping of existing landslide features, but does not include areas of potential future landslide susceptibility (i.e. slopes which have not yet failed), or areas which may be impacted by the runout of landslide debris. Additionally, the mapped landslide features may be currently inactive (i.e. not active since prehistoric times) and therefore not necessarily posing a high threat.

However, the spatial distribution of exposure to existing landslide features would be expected to have a reasonable correlation to exposure to areas of potential future landslide occurrence, as the presence of numerous existing landslide features likely indicates geological conditions are such that future landsliding is possible in the vicinity.

Table 5.12: Landslide hazard exposure summary for the Otago region, showing the estimated count and percentage of those elements within each district within the extent of mapped landslide features.

District	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in district
	Count	Percent of population in district	Count (all buildings)	Percent of total buildings in district	Count (Dwellings)	Percent of total dwellings in district	Count	Percent of total CCF in district	Very Low	Low	Mod.	High	Very High	
Dunedin City	6,160	4.8	4,380	4.9	1,981	4.4	1	3.3	52	3	24	25	13	117
Queenstown-Lakes	1,663	3.5	1,531	4.2	761	3.9	2	15.4	32	7	12	11	7	69
Central Otago	116	0.5	411	1.4	40	0.4	0	0.0	38	3	7	4	0	52
Waitaki	92	0.4	243	0.9	60	0.7	0	0.0	40	1	7	1	0	49
Clutha	8	0.0	27	0.1	2	0.0	0	0.0	63	0	1	0	0	64
Otago Total	8,038		6,592		2,844		3		225	14	51	41	20	351

Table 5.13: Landslide hazard exposure summary for the Top 10 urban areas or rural settlements in the Otago region, identified and ordered by the estimated population exposed to the hazard within that urban area/settlement.

Location	District	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in location
		Count	Percent of population in location	Count (all buildings)	Percent of total buildings in location	Count (Dwellings)	Percent of total dwellings in location	Count	Percent of total CCF in location	Very Low	Low	Mod.	High	Very High	
Dunedin	Dunedin City	5,025	5.0	2,673	4.5	1,561	4.5	1	5	24	0	9	7	11	51
Wanaka	Queenstown-Lakes	1,064	8.9	965	9.7	560	9.0	2	67	2	0	0	1	3	6
Warrington	Dunedin City	530	96.6	612	93.7	225	96.6	0	0	0	0	0	0	1	1
Queenstown	Queenstown-Lakes	494	2.0	273	2.2	158	1.9	0	0	3	0	5	2	3	13
Mosgiel	Dunedin City	64	0.4	43	0.4	24	0.4	0	0	4	0	0	2	0	6
Moeraki	Waitaki	49	31.1	130	27.4	51	31.1	0	0	0	0	0	1	0	1
Roxburgh	Central Otago	47	7.4	43	6.0	25	7.6	0	0	0	0	0	1	0	1
Brighton	Dunedin City	12	0.8	9	0.7	5	0.8	0	0	0	0	0	1	0	1
Karitane	Dunedin City	11	2.6	10	1.3	8	2.6	0	0	0	0	0	1	0	1
Waitati-Doctors Point	Dunedin City	3	0.4	1	0.2	1	0.4	0	0	0	0	1	0	0	1

5.1.8 Rockfall Hazard

There are a total of 1,200 people and 1,000 buildings, including nearly 400 dwellings, within the Otago region located in areas identified as being in areas exposed to potential rockfall hazard (Table 5.14). This analysis is based on mapping of 'rockfall awareness areas' by Easterbrook-Clarke *et al* (2022) which include the extent of modelled rockfall trajectories and a buffer to account for modelling uncertainties. No critical community facilities in the region are located in rockfall hazard areas.

A large majority of the population (84%) and buildings (76%) exposed to potential rockfall hazards are located within the Queenstown Lakes district.

A top-10 list of the urban areas or rural settlements exposed to rockfall hazards are shown in Table 5.15. This table shows the ten urban areas or rural settlements in the region assessed as having the greatest population being located within mapped rockfall awareness areas.

Rockfall hazard exposure for each 'community area' has been classed using the criteria in Table 3.2, with 18 (~5%) of the 351 community areas in the region classified with a 'high' or 'very high' exposure to rockfall hazard (Table 5.14).

Table 5.14: Rockfall hazard exposure summary for the Otago region, showing the estimated count and percentage of those elements within each district within the extent of rockfall awareness areas and potentially exposed to rockfall impact.

District	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in district
	Count	Percent of population in district	Count (all buildings)	Percent of total buildings in district	Count (Dwellings)	Percent of total dwellings in district	Count	Percent of total CCF in district	Very Low	Low	Mod.	High	Very High	
Queenstown-Lakes	1,040	2.2	810	2.2	303	1.6	0	0.0	32	9	15	9	4	69
Dunedin City	165	0.1	152	0.2	64	0.1	0	0.0	102	1	10	4	0	117
Central Otago	29	0.1	57	0.2	10	0.1	0	0.0	44	3	4	1	0	52
Clutha	0	0.0	21	0.1	0	0.0	0	0.0	63	1	0	0	0	64
Waitaki	0	0.0	16	0.1	0	0.0	0	0.0	49	0	0	0	0	49
Otago Total	1,234		1,056		377		0		290	14	29	14	4	351

Table 5.15: Rockfall hazard exposure summary for the Top 10 urban areas or rural settlements in the Otago region, identified and ordered by the estimated population exposed to the hazard within that urban area/settlement.

Location	District	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in location
		Count	Percent of population in location	Count (all buildings)	Percent of total buildings in location	Count (Dwellings)	Percent of total dwellings in location	Count	Percent of total CCF in location	Very Low	Low	Mod.	High	Very High	
Queenstown	Queenstown-Lakes	887	3.5	514	4.1	237	2.9	0	0	4	1	3	2	3	13
Dunedin	Dunedin City	125	0.1	80	0.1	48	0.1	0	0	42	0	6	3	0	51
Arrowtown	Queenstown-Lakes	60	2.1	48	2.1	29	2.1	0	0	0	0	0	1	0	1
Wanaka	Queenstown-Lakes	14	0.1	22	0.2	6	0.1	0	0	4	1	0	1	0	6
Roxburgh	Central Otago	8	1.2	10	1.4	4	1.2	0	0	0	0	1	0	0	1
Aramoana	Dunedin City	4	2.9	10	3.8	2	2.9	0	0	0	0	1	0	0	1
Purakaunui	Dunedin City	3	1.5	11	2.3	2	1.5	0	0	0	0	1	0	0	1
Lake Roxburgh	Central Otago	0	0.0	5	3.5	0	0.0	0	0	0	1	0	0	0	1
Oamaru	Waitaki	0	0.0	4	0.0	0	0.0	0	0	8	0	0	0	0	8
Moeraki	Waitaki	0	0.0	1	0.2	0	0.0	0	0	1	0	0	0	0	1

5.1.9 Storm Surge Inundation Hazard

There are a total of 500 people and 1,100 buildings, including 200 dwellings, within the Otago region located in areas identified as being prone to coastal inundation from storm surge (Table 5.16). This analysis is based on the data layer 'storm surge affected areas – all scenarios' which includes scenarios of up to 500-year ARI events and a sea level rise scenarios of up to 50 cm above mean sea level. No critical community facilities in the region are located in areas exposed to this hazard.

A majority of the population (67%) and buildings (59%) exposed to storm surge inundation hazard are those located within the Dunedin City district, with lesser numbers in the Clutha district (33%, 39%) and minor exposure in the Waitaki district.

A top-10 list of the urban areas or rural settlements exposed to storm surge hazards are shown in Table 5.17. This table shows the ten urban areas or rural settlements in the region assessed as having the greatest population being located within mapped storm surge inundation areas.

Storm surge inundation hazard exposure for each 'community area' has been classed using the criteria in Table 3.2, with 11 (~5%) of the 230 community areas in the three coastal districts (Waitaki, Dunedin City, Clutha) classified with a 'high' or 'very high' exposure to storm surge hazard (Table 5.16).

Table 5.16: *Storm surge inundation hazard exposure summary for the Otago region, showing the estimated count and percentage of those elements within each district potentially exposed to storm surge impact.*

District	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in district
	Count	Percent of population in district	Count (all buildings)	Percent of total buildings in district	Count (Dwellings)	Percent of total dwellings in district	Count	Percent of total CCF in district	Very Low	Low	Mod.	High	Very High	
Dunedin City	336	0.3	664	0.7	136	0.3	0	0.0	102	2	5	8	0	117
Clutha	164	0.9	440	1.5	90	1.5	0	0.0	55	4	2	2	1	64
Waitaki	4	0.0	18	0.1	3	0.0	0	0.0	47	1	1	0	0	49
Central Otago	*Hazard not present*													52
Queenstown-Lakes	*Hazard not present*													69
Otago Total	504		1,122		229		0		325	7	8	10	1	351

Table 5.17: Storm surge inundation hazard exposure summary for the Top 10 urban areas or rural settlements in the Otago region, identified and ordered by the estimated population exposed to the hazard within that urban area/settlement.

Location	District	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in location
		Count	Percent of population in location	Count (all buildings)	Percent of total buildings in location	Count (Dwellings)	Percent of total dwellings in location	Count	Percent of total CCF in location	Very Low	Low	Mod.	High	Very High	
Dunedin	Dunedin City	111	0.1	195	0.3	23	0.1	0	0	45	1	3	2	0	51
Waikouaiti	Dunedin City	73	5.8	81	5.8	36	5.8	0	0	0	0	0	1	0	1
Purakaunui	Dunedin City	72	34.4	230	48.3	45	34.4	0	0	0	0	0	1	0	1
Pounawea	Clutha District	65	60.0	112	57.7	42	60.0	0	0	0	0	0	0	1	1
Taieri Mouth	Clutha District	52	15.7	103	18.3	29	15.7	0	0	0	0	0	1	0	1
Waitati-Doctors Point	Dunedin City	28	4.7	37	5.6	11	4.7	0	0	0	0	0	1	0	1
Brighton	Dunedin City	19	1.3	30	2.2	8	1.3	0	0	0	0	0	1	0	1
Karitane	Dunedin City	14	3.3	45	5.8	10	3.3	0	0	0	0	0	1	0	1
Kakanui	Waitaki	3	0.8	10	1.4	2	0.8	0	0	0	0	1	0	0	1
Moeraki	Waitaki	1	0.6	3	0.6	1	0.6	0	0	0	1	0	0	0	1

5.1.10 Tsunami Hazard

There are a total of 500 people and 1,100 buildings, including >250 dwellings, within the Otago region located in areas identified as being prone to tsunami impact (Table 5.18). This analysis is based on the data layer which combines modelled tsunami extents for three scenarios (Puysegur, and South America 100 and 500-year ARI), and includes a sea level rise scenario of up to 50 cm above mean sea level. No critical community facilities in the region are located in areas mapped as being

A majority of the population (60%) and buildings (61%) exposed to tsunami inundation hazard are those located within the Clutha district, with lesser numbers in the Dunedin City district (38%, 33%) and minor exposure in the Waitaki district.

A top-10 list of the urban areas or rural settlements exposed to tsunami hazards are shown in Table 5.19. This table shows the ten urban areas or rural settlements in the region assessed as having the greatest population being located within mapped tsunami inundation areas.

Tsunami inundation hazard exposure for each 'community area' has been classed using the criteria in Table 3.2, with 13 (~6%) of the 230 community areas in the three coastal districts (Waitaki, Dunedin City, Clutha) classified with a 'high' or 'very high' exposure to tsunami hazard (Table 5.18).

Table 5.18: Tsunami hazard exposure summary for the Otago region, showing the estimated count and percentage of those elements within each district potentially exposed to tsunami impact.

District	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in district
	Count	Percent of population in district	Count (all buildings)	Percent of total buildings in district	Count (Dwellings)	Percent of total dwellings in district	Count	Percent of total CCF in district	Very Low	Low	Mod.	High	Very High	
Clutha	303	1.7	697	2.3	164	2.7	0	0.0	52	2	2	7	1	64
Dunedin City	191	0.1	378	0.4	95	0.2	0	0.0	108	0	4	5	0	117
Waitaki	11	0.0	55	0.2	7	0.1	0	0.0	46	2	1	0	0	49
Central Otago	*Hazard not present*													52
Queenstown-Lakes	*Hazard not present*													69
Otago Total	504		1,130		266		0		327	4	7	12	1	351

Table 5.19: Tsunami hazard exposure summary for the Top 10 urban areas or rural settlements in the Otago region, identified and ordered by the estimated population exposed to the hazard within that urban area/settlement.

Location	District	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in location
		Count	Percent of population in location	Count (all buildings)	Percent of total buildings in location	Count (Dwellings)	Percent of total dwellings in location	Count	Percent of total CCF in location	Very Low	Low	Mod.	High	Very High	
Pounawea	Clutha District	103	95.7	186	95.9	67	95.7	0	0	0	0	0	0	1	1
Taieri Mouth	Clutha District	68	20.5	144	25.5	38	20.5	0	0	0	0	0	1	0	1
Purakaunui	Dunedin City	55	26.0	164	34.5	34	26.0	0	0	0	0	0	1	0	1
Brighton	Dunedin City	52	3.6	59	4.3	22	3.6	0	0	0	0	0	1	0	1
Waikouaiti	Dunedin City	24	1.9	20	1.4	15	2.4	0	0	0	0	0	1	0	1
KaritÄ• ne	Dunedin City	21	5.0	50	6.5	12	4.0	0	0	0	0	0	1	0	1
Waitati-Doctors Point	Dunedin City	21	3.4	22	3.3	12	5.2	0	0	0	0	0	1	0	1
Kaka Point	Clutha District	15	6.4	26	6.4	8	4.3	0	0	0	0	0	1	0	1
Kaitangata	Clutha District	12	1.4	9	1.0	6	1.7	0	0	0	0	0	1	0	1
Kakanui	Waitaki	10	2.3	28	3.9	5	1.9	0	0	0	0	1	0	0	1

5.1.11 Coastal Erosion Hazard

There are a total of around 40 people and 110 buildings, including about 20 dwellings, within the Waitaki District located in areas identified as being prone to coastal erosion impact (Table 5.20). This analysis is based on a modelled future shoreline position where there is a 5% probability of erosion extending up to or landward of this position over the 100-year outlook period.

Exposure analysis was not carried out for the Dunedin City or Clutha districts as this type of coastal erosion modelling dataset is not currently available.

No critical community facilities in the Waitaki District are located in areas mapped as being prone to coastal erosion inundation.

A list of the urban areas or rural settlements in the Waitaki District exposed to coastal erosion hazard are shown in Table 5.21. This table shows four urban areas or rural settlements in the district assessed as having some population or buildings being located within mapped coastal erosion areas. A significant portion (50%) of the population and buildings (29%) exposed to potential coastal erosion are those located in rural areas outside of these urban boundaries.

Coastal erosion hazard exposure for each ‘community area’ has been classed using the criteria in Table 3.2, with only ~2% of the 49 community areas in the Waitaki district classified with a ‘high’ or ‘very high’ exposure to coastal erosion hazard (Table 5.20).

Table 5.20: Coastal erosion hazard exposure summary for the Otago region, showing the estimated count and percentage of those elements within the Waitaki district potentially exposed to coastal erosion impact

District	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in district
	Count	Percent of population in district	Count (all buildings)	Percent of total buildings in district	Count (Dwellings)	Percent of total dwellings in district	Count	Percent of total CCF in district	Very Low	Low	Mod.	High	Very High	
Waitaki	37	0.2	111	0.4	18	0.2	0	0.0	44	1	3	1	0	49
Dunedin City	*Data not available*													117
Clutha	*Data not available*													64
Central Otago	*Hazard not present*													52
Queenstown-Lakes	*Hazard not present*													69
Otago Total														351

Table 5.21: Coastal erosion hazard exposure summary for the four urban areas or rural settlements exposed in the Waitaki District, identified and ordered by the estimated population exposed to the hazard within that urban area/settlement.

Location	District	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in location
		Count	Percent of population in location	Count (all buildings)	Percent of total buildings in location	Count (Dwellings)	Percent of total dwellings in location	Count	Percent of total CCF in location	Very Low	Low	Mod.	High	Very High	
Oamaru	Waitaki	10	0.1	27	0.3	4	0.1	0	0	0	0	2	0	6	8
Moeraki	Waitaki	7	4.3	38	8.0	7	4.3	0	0	0	0	1	0	0	1
Kakanui	Waitaki	2	0.4	10	1.4	1	0.4	0	0	0	0	0	1	0	1
Hampden	Waitaki	0	0.0	4	0.6	0	0.0	0	0	0	0	0	0	1	1

6 Summary and Next Steps

6.1 Summary

This report presents findings of Otago Regional Council's (ORC's) first systematic analysis of natural hazard exposure for Otago. The report provides a 'stocktake' and baseline of the current understanding of natural hazard exposure for the region, and is a first iteration of analysis to quantify and map natural hazards exposure in Otago at a regional scale.

This report enumerates the exposure of three elements at risk: population, buildings and 'critical community facilities' to nine natural hazard types, and classifies natural hazard exposure levels for each hazard, for each of 351 community areas in the region. Together the exposure classification and enumeration enables a spatial mapping of natural hazards exposure in the region, and comparison of natural hazards exposure between hazard types, and between districts or urban areas.

6.2 Next Steps

Following completion of this regional natural hazards exposure analysis, there are two main next steps in ORC's region-wide natural hazards risk programme;

1. Natural hazards prioritisation for the Otago region, and
2. Review and possible revision of this region-wide natural hazards exposure analysis.

6.2.1 Natural Hazards Prioritisation

ORC has developed a natural hazards prioritisation approach, which will enable a systematic identification and definition of key projects and allocation of work within the Natural Hazards work programme (van Woerden *et al*, 2024). The outputs from implementation of the prioritisation approach will be a key factor in the development of ORC's Natural Hazards work programme through the Long-term Plan (LTP) process, through providing a guide to the relative priority and scale of the possible projects considered for inclusion. This prioritisation approach includes development of a preliminary risk analysis for each long-listed geographic location.

The findings of the exposure analysis presented in this report will be one source of information which will inform the prioritisation approach, which will also include reference to a much wider range of other information available (Figure 6.1). The prioritisation process is intended to be completed by mid-2026.

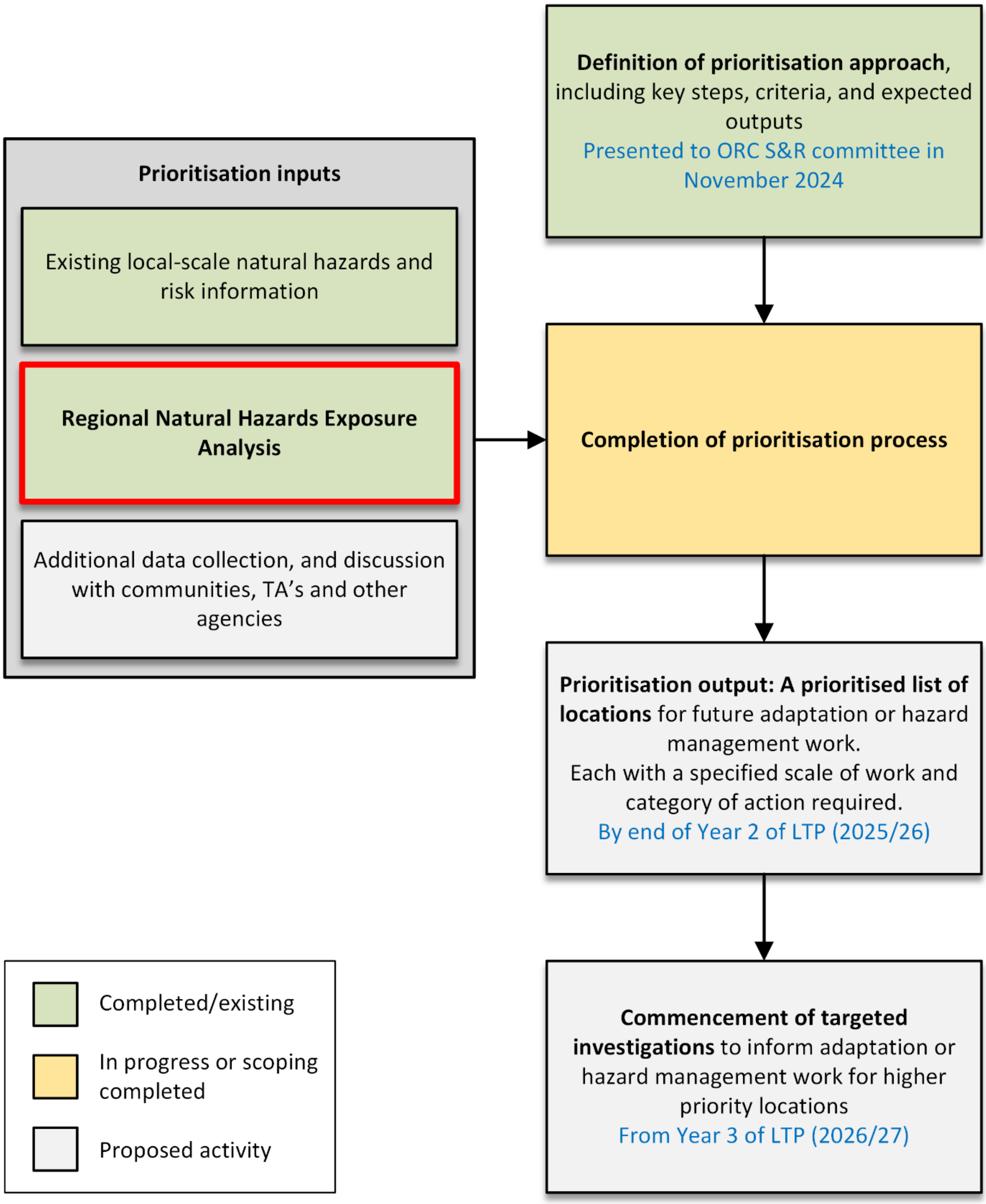

Figure 6.1: Flow chart showing key activities and programme sequencing in the natural hazards risk assessment and prioritisation programme. The exposure analysis presented in this report is highlighted red.

6.2.2 Review and revision of region-wide exposure analysis

Revision of natural hazards exposure analysis and reporting will be undertaken periodically (no longer than 6-yearly) as substantive new or updated natural hazards mapping or elements at risk datasets become available. Additional datasets which could be included in future iterations of this exposure analysis include;

6.2.2.1 NATURAL HAZARDS MAPPING DATA

- Incorporation of higher-resolution project-scale natural hazards information for locations where this is available. For example, locations where more detailed local-scale flooding or debris flow hazard modelling have been completed, or where data held by territorial authorities may be suitable for inclusion.

- Incorporation of national-scale natural hazards datasets such as several studies currently in progress or recently completed, for example;
    - GNS Science's national-scale landslide susceptibility modelling (Sliding Lands Hōretireti Whenua)
    - NIWA's national-scale fluvial-pluvial flood mapping project (Mā te haumaru ō te wai) which aims to develop consistent nationwide flood hazard maps and also to consider the effects of climate change.
    - NIWA's coastal flood mapping, which provides modelled representation for a 1% annual exceedance probability (AEP) extreme sea level flooding under current climatic sea conditions, plus relative sea level rise up to 2m above present-day mean sea level (Stephens and Paulik, 2023).
    - Tonkin + Taylor Ltd are developing a national liquefaction model, which will provide a nationally consistent way to describe and measure liquefaction risk.

- Several existing ORC natural hazard mapping datasets (e.g. alluvial fan mapping) are based on geomorphic interpretation but were compiled prior to the widespread availability of high-resolution topographic data (i.e. LiDAR). ORC can consider refinement of those mapping layers when there is more comprehensive LiDAR coverage available in the region, and revised hazards datasets can be incorporated into future iterations of analysis.

- The Natural Hazards Commission Toka Tū Ake (formerly EQC) holds a dataset of ~5,000 settled damage claims for the Otago region (dated 1997-present), each classified by hazard type and linked to a specific address. Analysis of this dataset would identify locations of known natural hazards impact, complementing analysis based on mapped natural hazards extents.

6.2.2.2 ELEMENTS AT RISK DATA

- Revision and updating of elements at risk information such as updating with future census data, and refinement of population estimation and building classification approaches.

- Possible inclusion of additional types of elements or data such as demographic information (e.g. age), social or cultural assets (e.g. schools, marae), lifelines infrastructure (EMO, 2018; Toa Consulting, 2024), social vulnerability indicators (e.g. EHINZ, 2024), or monetary values (e.g. building value).

7 List of Abbreviations

7.1 Abbreviations

Abbreviation	*Explanation*
AEP	Annual exceedance probability
ARI	Average recurrence interval
EMO	Emergency Management Otago
EQC	EQC Toka Tū Ake, Earthquake Commission (renamed the Natural Hazards Commission, NHC from 1 July 2024)
GIS	Geographic Information System
GNS	GNS Science, a Crown Research Institute
LiDAR	Light Detection and Ranging, a remote sensing method for topographic survey
LINZ	Land Information New Zealand
NIWA	National Institute of Water & Atmospheric research
NSHM	National Seismic Hazard Model
ORC	Otago Regional Council
pORPS/RPS	Proposed Otago Regional Policy Statement
SA	Statistical Area
SSP	Shared socio-economic pathways, scenarios for a range of plausible societal and climatic futures

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9 Appendices

9.1 Appendix A. Natural Hazard Mapping

Summary images to show approximate location and extent of mapping coverage for each hazard type used in exposure analysis. Note that the images for tsunami, storm surge and coastal erosion have a buffer added to the hazard polygon to enable visibility at this scale of map display.

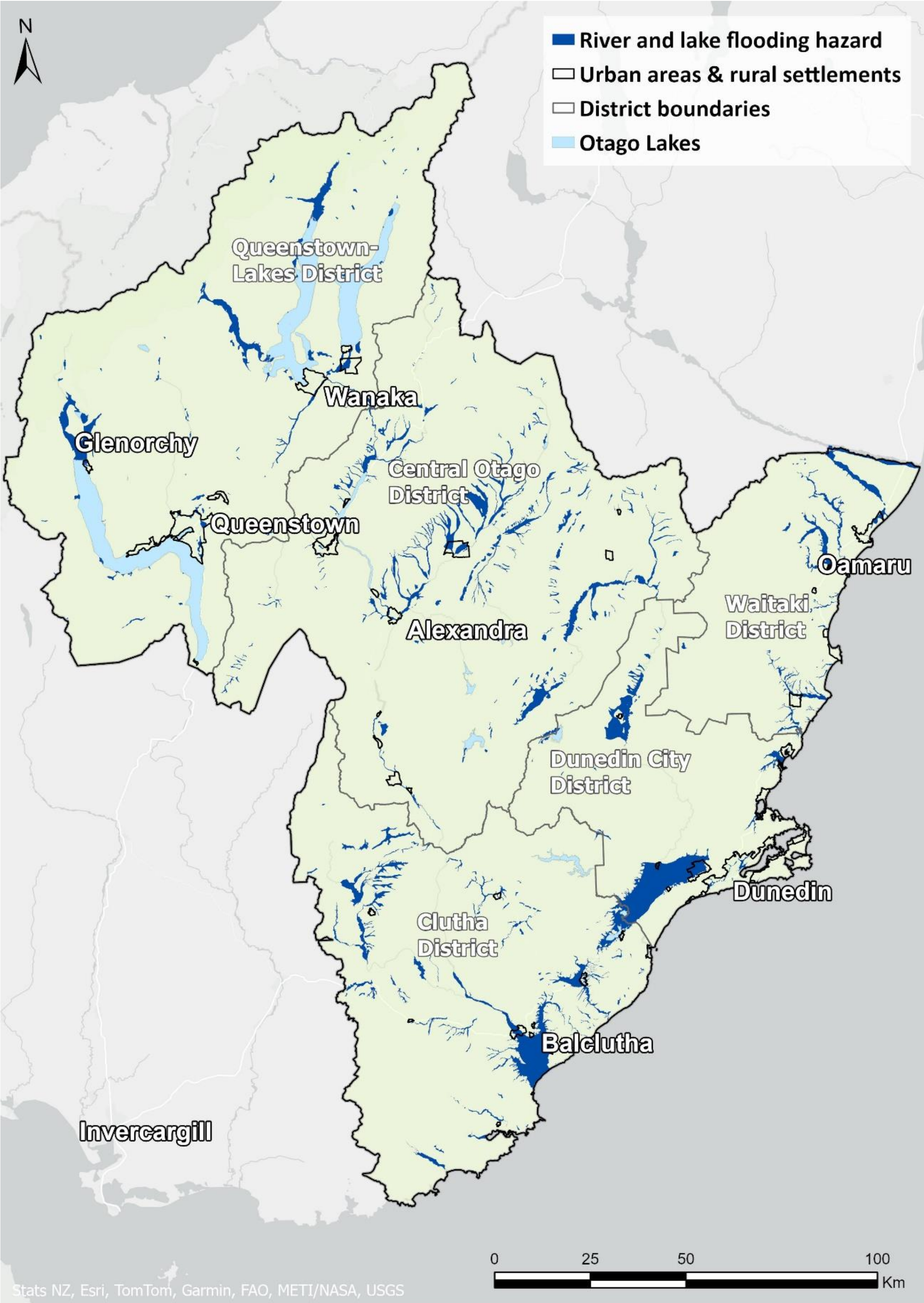

Figure 9.1: River and lake flooding mapping dataset used in Otago natural hazard exposure analysis.

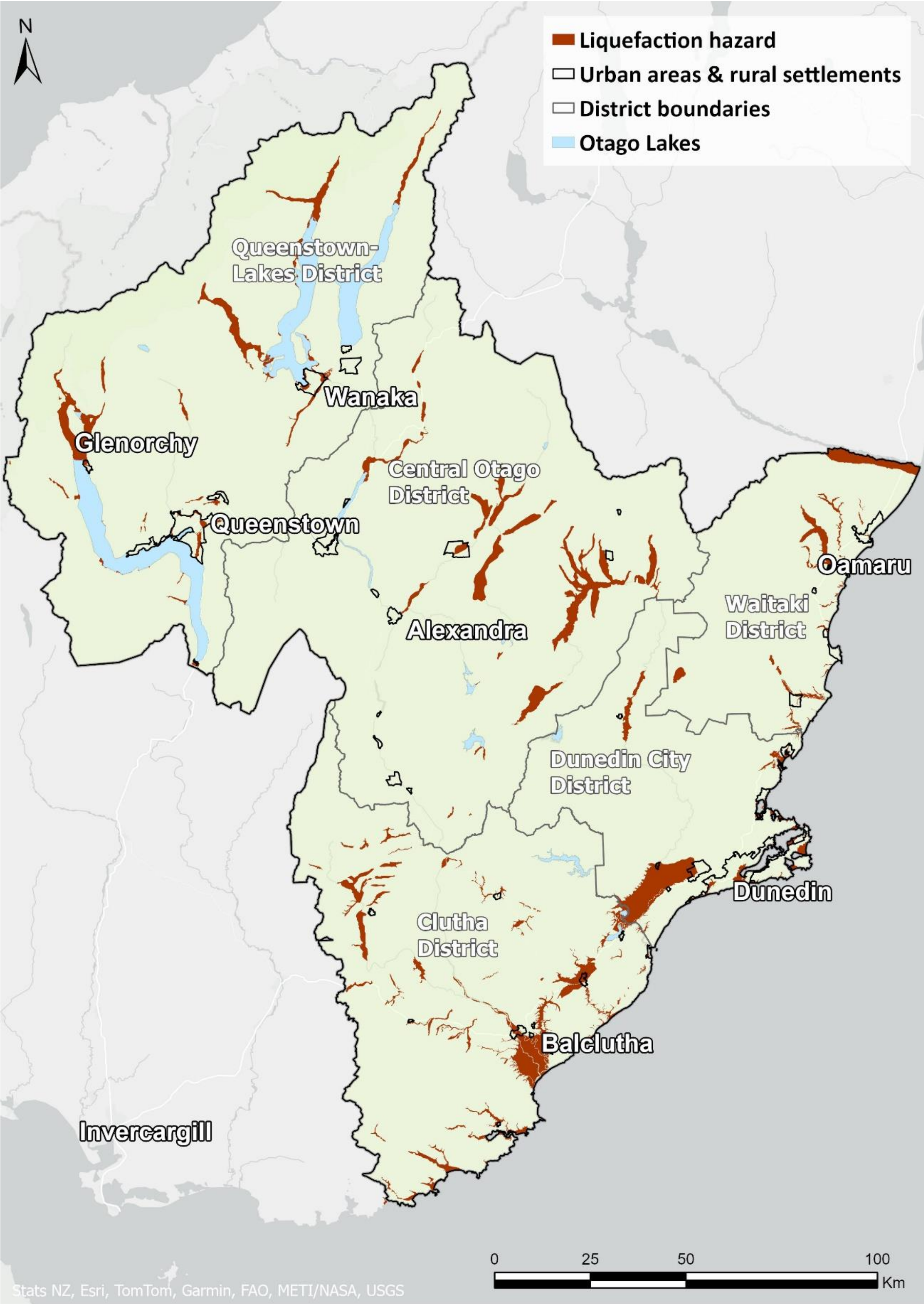

Figure 9.2: Liquefaction susceptibility mapping dataset used in Otago natural hazard exposure analysis.

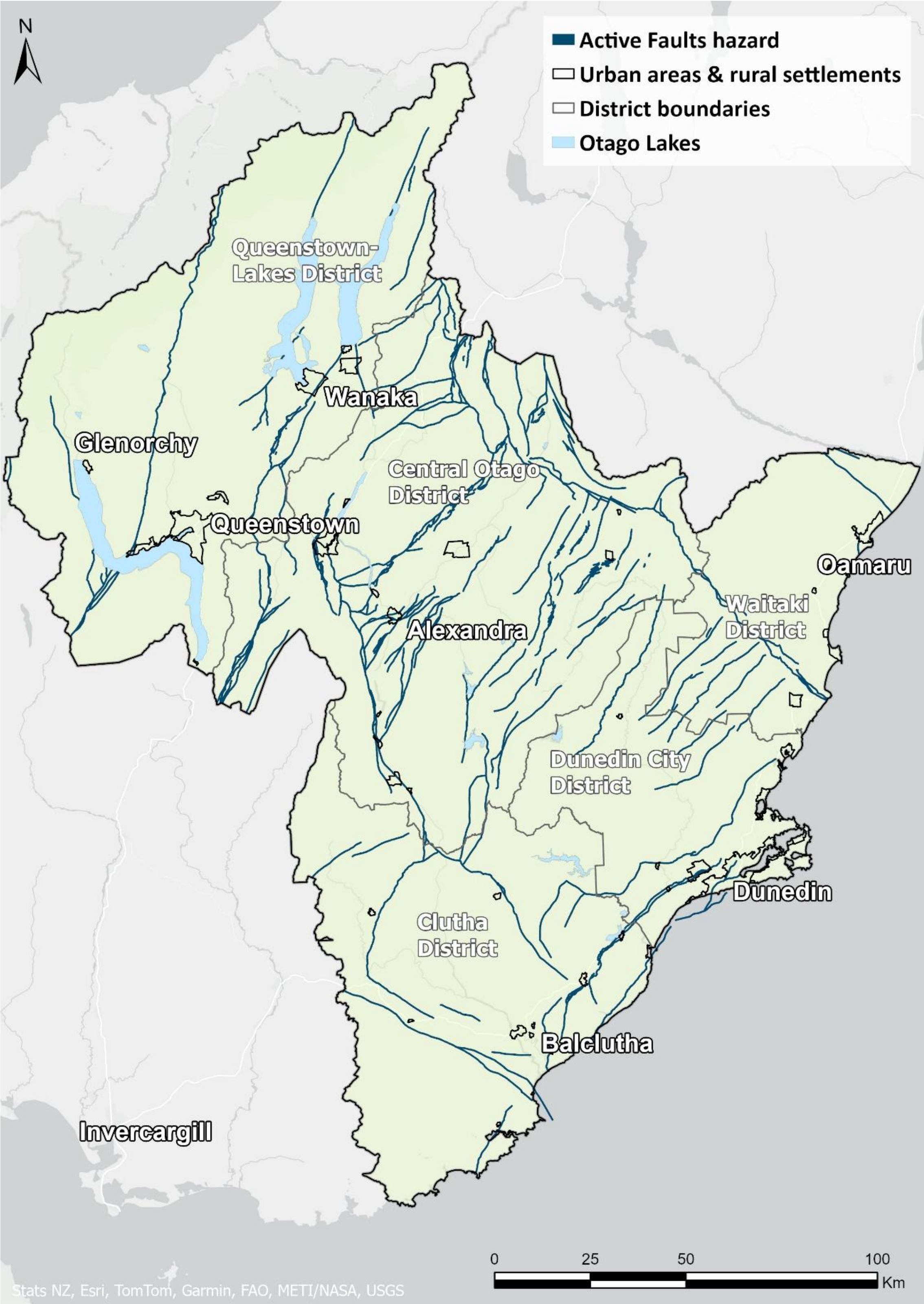

Figure 9.3: Active fault mapping dataset used in Otago natural hazard exposure analysis.

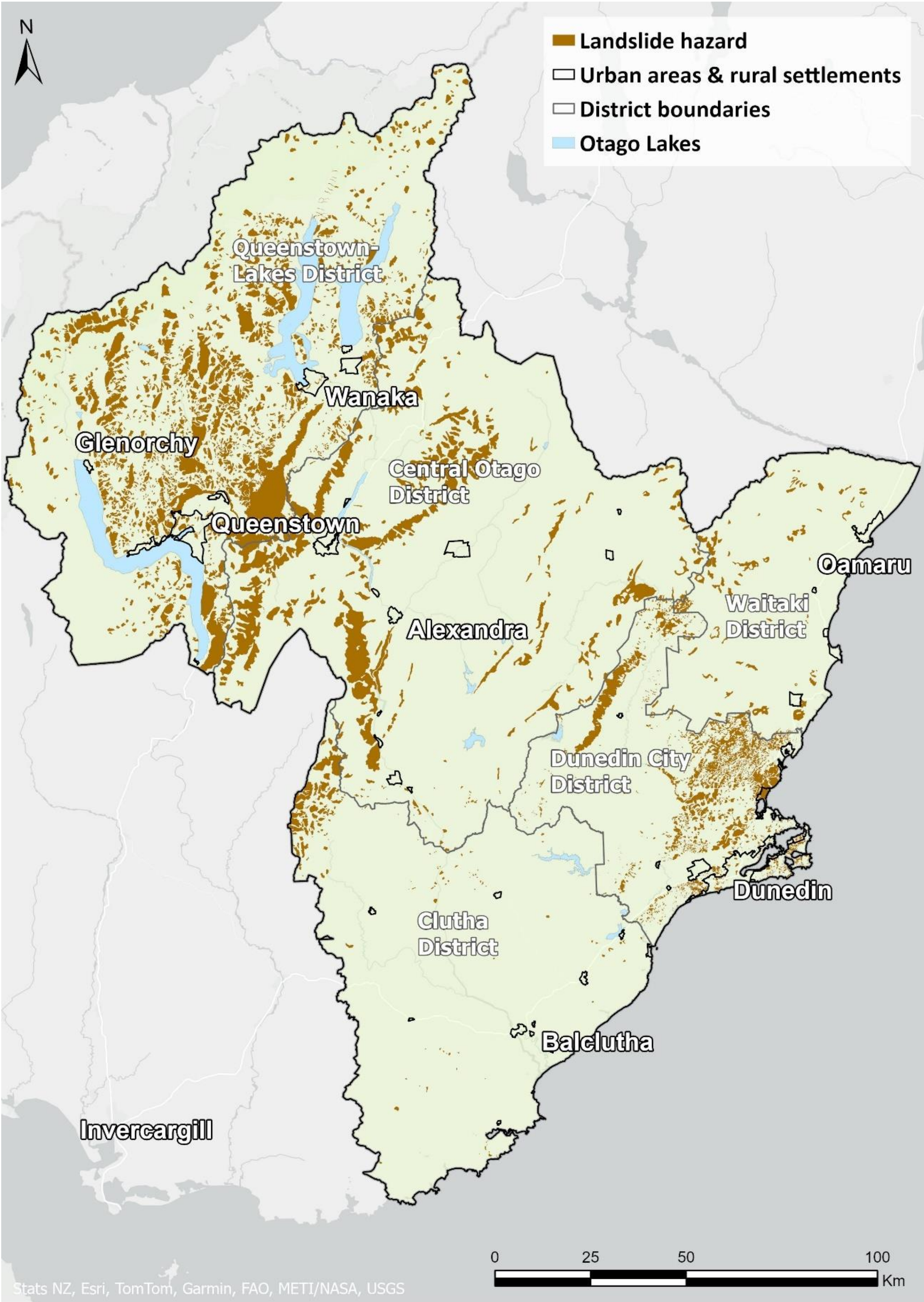

Figure 9.4: Landslide features mapping dataset used in Otago natural hazard exposure analysis.

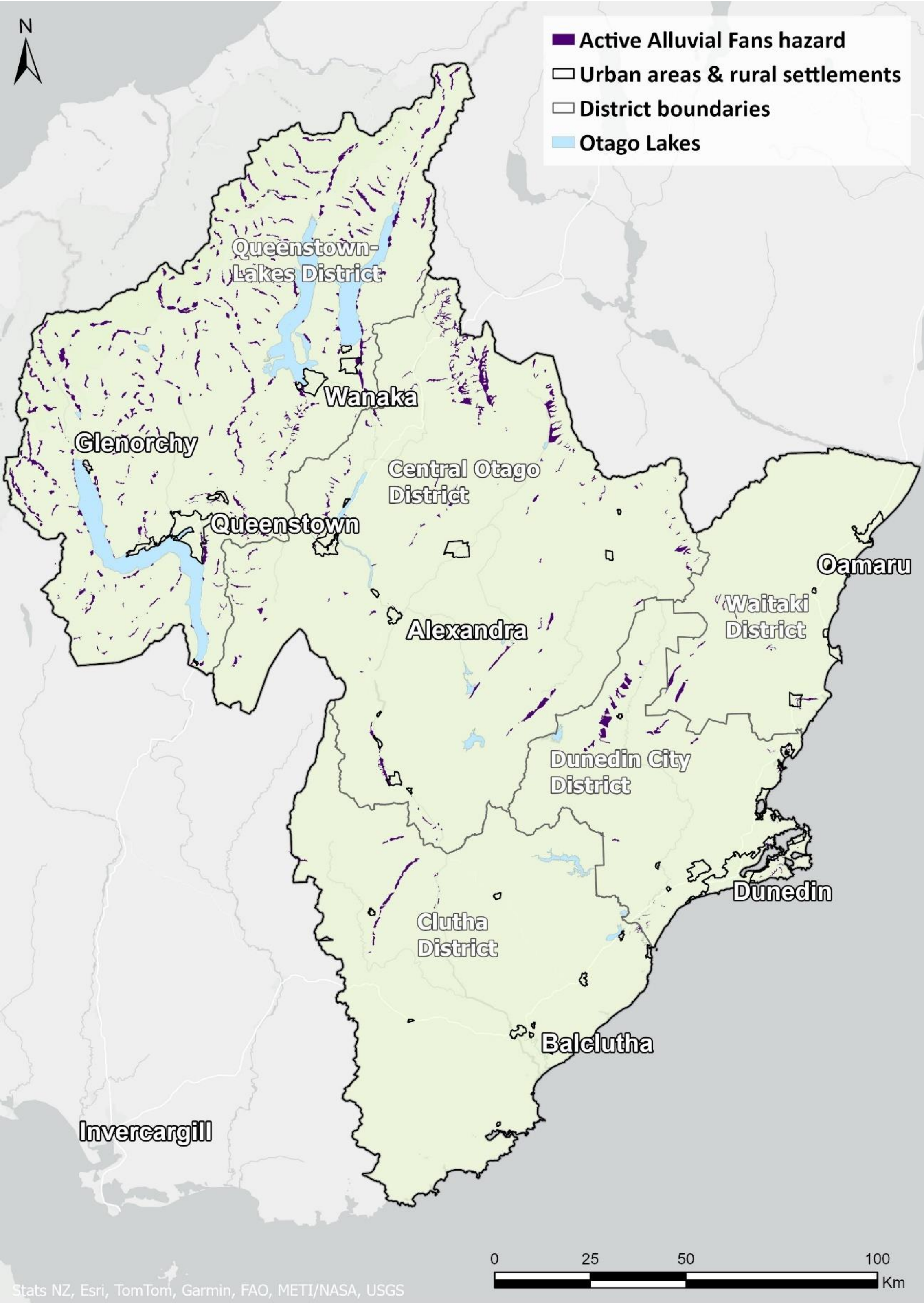

Figure 9.5: Active alluvial fan mapping dataset used in Otago natural hazard exposure analysis, showing 'debris-dominated' or 'composite' fan surfaces, but excluding those solely characterised as 'floodwater-dominated' which have been included within analysis of flooding hazards.

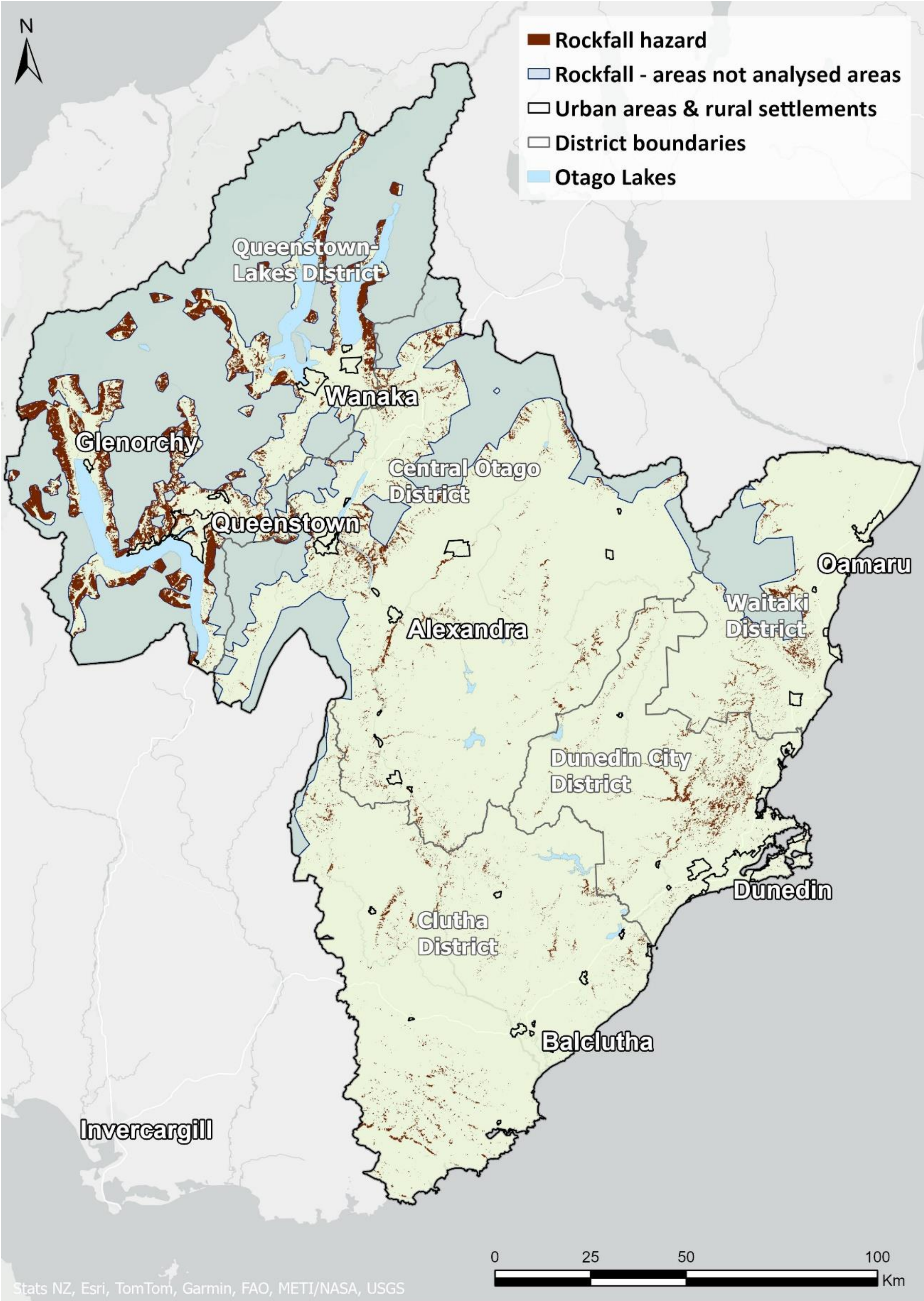

Figure 9.6: Rockfall awareness areas mapping dataset used in Otago natural hazard exposure analysis. Note that mapping coverage excludes catchments devoid of buildings or roads, or with only very sparsely distributed buildings.

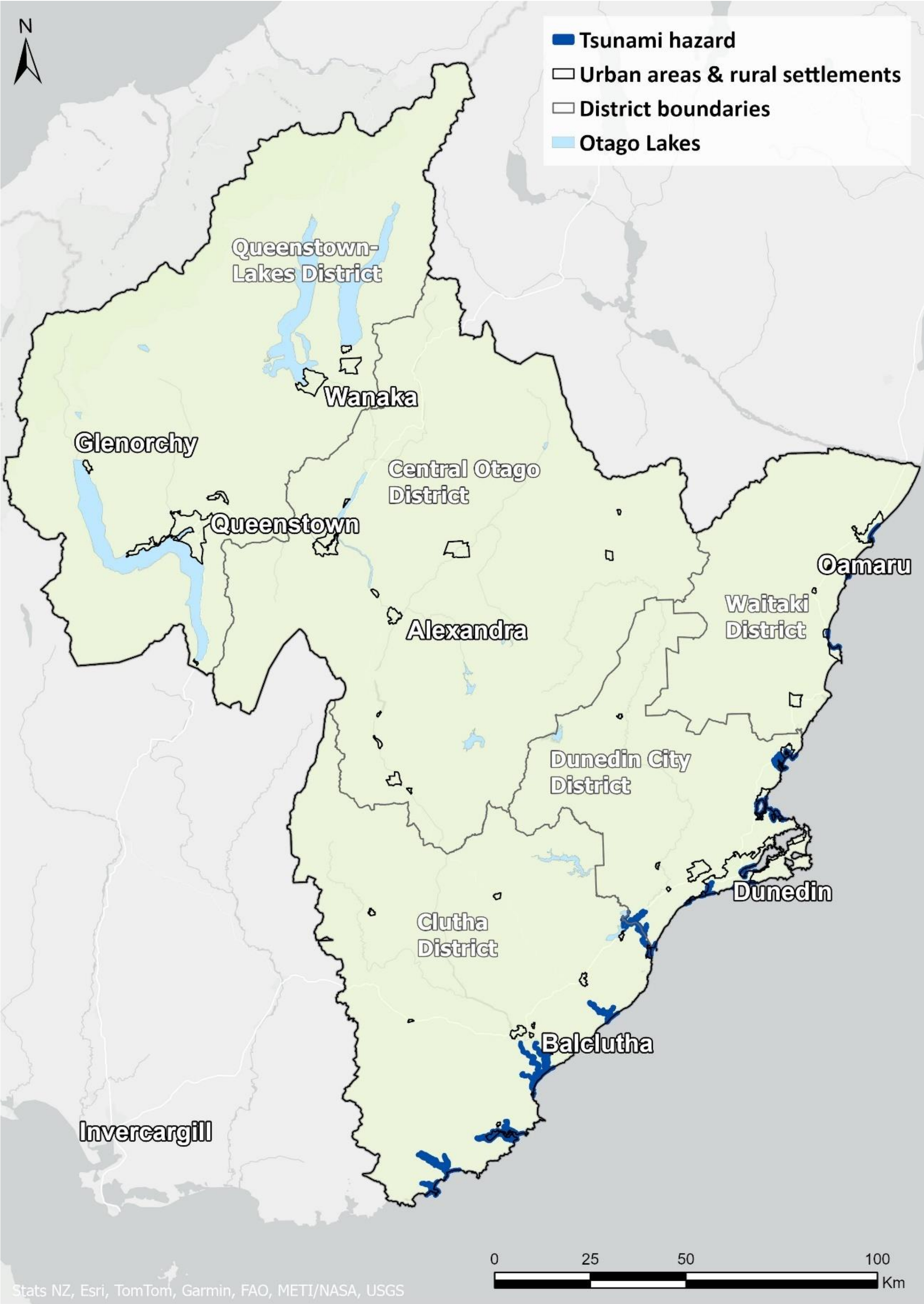

Figure 9.7: Tsunami hazard mapping dataset used in Otago natural hazard exposure analysis. A buffer has been added to the hazard polygon to enable visibility at this scale of map display.

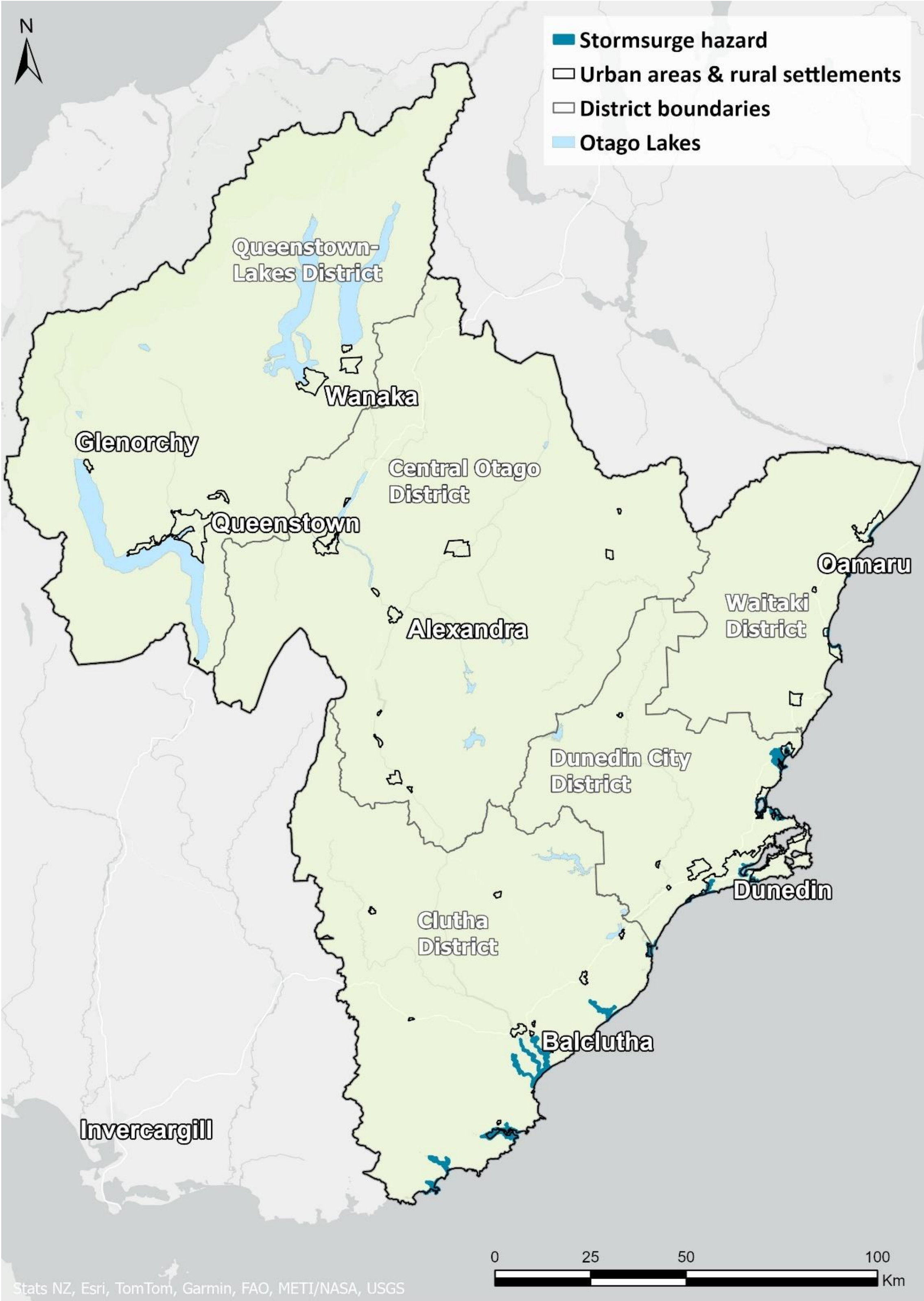

Figure 9.8: Storm surge inundation hazard mapping dataset used in Otago natural hazard exposure analysis. A buffer has been added to the hazard polygon to enable visibility at this scale of map display.

Figure 9.9: Coastal erosion hazard mapping dataset for the Waitaki District used in Otago natural hazard exposure analysis. A buffer has been added to the hazard polygon to enable visibility at this scale of map display.

9.2 Appendix B. Geographic Units

9.2.1 Description of Statistical Units

Table 9.1: Description of the Stats NZ statistical units.

Unit	*Description*
Meshblock	The smallest geographic unit for which statistical data is collected and processed by Stats NZ, varying in size from part of a city block to a large area of rural land. Meshblock units are not used in this current natural hazards analysis.
Statistical Area 1 (SA1)	SA1 is a geographic area built by joining meshblocks. SA1s have an ideal size range of 100-200 residents, and a maximum population of about 500. There are 1641 SA1 areas within the Otago region, of which 214 are located outside of urban areas or rural settlements.
Statistical Area 2 (SA2)	SA2 is a geographic area which aggregates SA1s, and is designed to represent a 'community of place' where people interact together socially and economically. SA2s in city council areas generally have a population of 2,000–4,000 residents while SA2s in district council areas generally have a population of 1,000–3,000 residents. There are 132 SA2 areas within the Otago region, of which 119 are within urban areas or rural settlements.
Urban / Rural	A geography which identifies urban-rural boundaries. • Urban areas (small, medium, large, major) • Rural settlement • Other rural

9.2.2 Urban areas and rural settlements and rural Otago community units

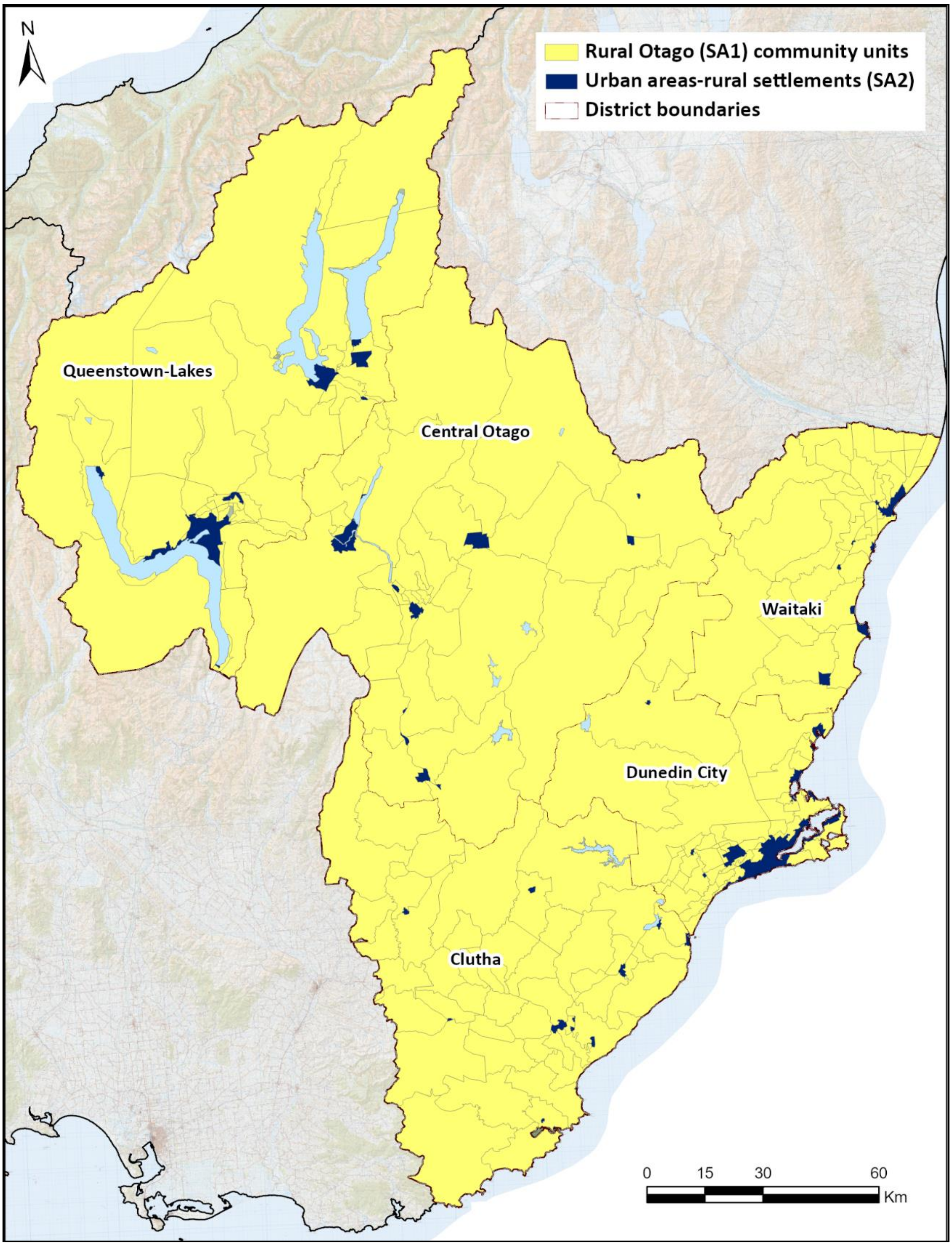

Figure 9.10: Illustration of the urban areas and rural settlement boundaries (blue) and rural Otago community areas (yellow) used in Otago natural hazard exposure analysis.

9.2.3 Otago urban areas and rural settlements

Table 9.2: List of Otago urban areas and rural settlements used in used in Otago natural hazard exposure analysis (Stats NZ, 2022).

Geography	Count	Locations	
Major Urban Area (>100,000 residents)	1	Dunedin	
Large Urban Area (30,000-99,999 residents)	0	None within Otago	
Medium Urban Area (10,000-29,999 residents)	4	Mosgiel Oamaru	Queenstown Wanaka
Small Urban Area (1,000-9,999 residents)	9	Alexandra Arrowtown Balclutha Brighton Clyde	Cromwell Lake Hawea Milton Waikouaiti
Rural Settlement	40	Allanton Aramoana Bannockburn Benhar Clinton Ettrick Glenorchy Hampden Harwood Hawea Flat Herbert Kaitangata Kaka Point Kakanui Karitane Kingston Lake Roxburgh Village Lawrence Luggate Maheno	Middlemarch Millbrook Millers Flat Moeraki Naseby Omakau Outram Owaka Palmerston Pisa Moorings Pounawea Purakaunui Ranfurly Roxburgh Stirling Taieri Mouth Tapanui Waihola Waitati-Doctors Point Warrington

9.3 Appendix C. Critical Community Facilities

Table 9.3: List of the 90 critical community facilities (CCF) used in Otago natural hazard exposure analysis.

Police Station (26)	***Fire Station (44)***	***Hospital (4)***	***Ambulance Station (10)***	***ECC and EOC (6)***
Alexandra Arrowtown Balclutha Clinton Cromwell Dunedin Central & Southern Police District HQ Dunedin North Dunedin South Hampden Kaikorai Lawrence Middlemarch Milton Mosgiel Oamaru Omakau Owaka Palmerston Port Chalmers Portobello Queenstown Ranfurly Roxburgh Tapanui Waikouaiti Wanaka	Alexandra Arrowtown Balclutha Brighton Clinton Clutha Valley Clyde Cromwell Dunedin Central Frankton Heriot Kaitangata Kaka Point Lake Hawea Lawrence Lookout Point Luggate Middlemarch Millers Flat Milton Mosgiel Naseby Oamaru Naseby Oamaru Omakau Outram Owaka Palmerston Port Chalmers Portobello Queenstown Ranfurly Ravensbourne Roslyn Roxburgh St Kilda Tapanui Waikouaiti Waitahuna Waitati Wakari Rural Waiwera South Wanaka Weston Willowbank	Dunedin Hospital Dunstan Hospital Lakes District Hospital Wakari Hospital	Alexandra Balclutha Cromwell Dunedin Central Frankton Lawrence Milton Mosgiel Oamaru Wanaka	ECC (Dunedin) EOC (Waitaki) EOC (Dunedin city) EOC (Clutha) EOC (Central Otago) EOC (Queenstown Lakes)

9.4 Appendix D. Additional Natural Hazards Exposure Results

9.4.1 Natural Hazards Exposure Summary per District

Table 9.4: Natural hazards exposure summary for the Waitaki District, showing the estimated count and percentage of those elements within the district potentially exposed to impact from the named natural hazard types.

Hazard type	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in district
	Count	Percent of population in district	Count (all buildings)	Percent of total buildings in district	Count (Dwellings)	Percent of total dwellings in district	Count	Percent of total CCF in district	Very Low	Low	Moderate	High	Very High	
River and lake flooding	2,707	12.5	2,870	11.2	924	11.3	0	0.0	21	5	9	10	4	49
Liquefaction	992	4.6	1,967	7.7	268	3.3	3	37.5	17	2	15	10	5	49
Active Faults	497	2.3	729	2.8	101	1.2	0	0.0	35	1	5	6	2	49
Landslide	92	0.4	243	0.9	60	0.7	0	0.0	40	1	7	1	0	49
Alluvial fan	238	1.1	451	1.8	102	1.3	1	12.5	46	0	2	0	1	49
Rockfall	0	0.0	16	0.1	0	0.0	0	0	49	0	0	0	0	49
Tsunami	11	0.0	55	0.2	7	0.1	0	0	46	2	1	0	0	49
Storm surge	4	0.0	18	0.1	3	0.0	0	0	47	1	1	0	0	49
Coastal erosion	37	0.2	111	0.4	18	0.2	0	0	44	1	3	1	0	49

Table 9.5: Natural hazards exposure summary for the Dunedin City District, showing the estimated count and percentage of those elements within the district potentially exposed to impact from the named natural hazard types.

Hazard type	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in district
	Count	Percent of population in district	Count (all buildings)	Percent of total buildings in district	Count (Dwellings)	Percent of total dwellings in district	Count	Percent of total CCF in district	Very Low	Low	Moderate	High	Very High	
River and lake flooding	27,969	21.7	19,683	21.9	8,666	19.2	10	33.3	47	1	7	23	39	117
Liquefaction	30,128	23.4	23,924	26.7	10,673	23.7	14	46.7	48	1	11	16	41	117
Active Faults	13,748	10.7	10,158	11.3	5,273	11.7	3	10.0	73	7	4	11	22	117
Landslide	6,160	4.8	4,380	4.9	1,981	4.4	1	3.3	52	3	24	25	13	117
Alluvial fan	1,294	1.0	1,436	1.6	530	1.2	1	3.3	103	3	4	3	4	117
Rockfall	165	0.1	152	0.2	64	0.1	0	0.0	102	1	10	4	0	117
Tsunami	191	0.1	378	0.4	95	0.2	0	0	108	0	4	5		117
Storm surge	336	0.3	664	0.7	136	0.3	0	0	102	2	5	8	0	117

Table 9.6: Natural hazards exposure summary for the Central Otago District, showing the estimated count and percentage of those elements within the district potentially exposed to impact from the named natural hazard types.

Hazard type	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in district
	Count	Percent of population in district	Count (all buildings)	Percent of total buildings in district	Count (Dwellings)	Percent of total dwellings in district	Count	Percent of total CCF in district	Very Low	Low	Moderate	High	Very High	
River and lake flooding	1,466	6	2,591	9	523	5.2	2	11.8	6	4	10	29	3	52
Liquefaction	872	3.6	1,637	5.7	267	2.7	2	11.8	37	2	3	7	3	52
Active Faults	3,758	15.5	4,694	16.3	1,517	15.2	5	29.4	11	2	5	26	8	52
Landslide	116	0.5	411	1.4	40	0.4	0	0.0	38	3	7	4	0	52
Alluvial fan	734	3.0	1,063	3.7	256	2.6	0	0.0	34	3	3	11	1	52
Rockfall	29	0.1	57	0.2	10	0.1	0	0	44	3	4	1	0	52

Table 9.7: Natural hazards exposure summary for the Queenstown Lakes District, showing the estimated count and percentage of those elements within the district potentially exposed to impact from the named natural hazard types.

Hazard type	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count commu areas distri
	Count	Percent of population in district	Count (all buildings)	Percent of total buildings in district	Count (Dwellings)	Percent of total dwellings in district	Count	Percent of total CCF in district	Very Low	Low	Moderate	High	Very High	
River and lake flooding	2,883	6	3,161	8.7	1,387	7.2	1	7.7	29	8	14	14	4	69
Liquefaction	8,870	18.6	8,059	22.2	4,350	22.5	4	30.8	25	6	8	17	13	69
Active Faults	2,172	4.5	1,891	5.2	899	4.7	1	7.7	51	3	4	8	3	69
Landslide	1,663	3.5	1,531	4.2	761	3.9	2	15.4	32	7	12	11	7	69
Alluvial fan	3,189	6.7	2,862	7.9	1,104	5.7	1	7.7	29	3	6	24	7	69
Rockfall	1,040	2.2	810	2.2	303	1.6	0	0	32	9	15	9	4	69

Table 9.8: Natural hazards exposure summary for the Clutha District, showing the estimated count and percentage of those elements within the district potentially exposed to impact from the named natural hazard types.

Hazard type	Population exposed		Buildings exposed				Critical Community Facilities (CCF)		Count of community areas in each exposure class					Count of community areas in district
	Count	Percent of population in district	Count (all buildings)	Percent of total buildings in district	Count (Dwellings)	Percent of total dwellings in district	Count	Percent of total CCF in district	Very Low	Low	Moderate	High	Very High	
River and lake flooding	3,754	20.5	5,593	18.7	1,276	21.2	10	45.5	18	8	5	23	10	64
Liquefaction	5,184	28.3	7,442	24.8	1,901	31.6	14	63.6	15	7	8	18	16	64
Active Faults	1,774	10.0	2,624	8.8	581	9.7	1	4.5	33	6	3	17	5	64
Landslide	8	0.0	27	0.1	2	0.0	0	0.0	63	0	1	0	0	64
Alluvial fan	17	0.1	92	0.3	4	0.1	0	0.0	60	1	3	0	0	64
Rockfall	0	0.0	21	0.1	0	0.0	0	0	63	1	0	0	0	64
Tsunami	303	1.7	697	2.3	164	2.7	0	0	52	2	2	7	1	64
Storm surge	164	0.9	440	1.5	90	1.5	0	0	55	4	2	2	1	64

9.4.2 Exposure of Critical Community Facilities (CCF)

Table 9.9: Summary of critical community facilities (CCF) in the Otago region which are exposed to potential natural hazards within each district. The facilities listed are coloured by type; Medical (hospital or ambulance, in red), Police (blue), Fire (orange), or Emergency Coordination/Operations Centres (ECC or EOC, green). There are no critical community facilities identified in this study as being exposed to rockfall, tsunami, storm surge or coastal erosion hazards.

	Hazard type				
District	**River and lake flooding**	**Liquefaction**	**Active Faults**	**Landslide**	**Alluvial fan**
Dunedin City	St John Ambulance Mosgiel	Dunedin Hospital	Lookout Point Fire Station	GECC Group Emergency Coordination Centre	Portobello Fire Station
	Dunedin Hospital	St John Ambulance Mosgiel	Roslyn Fire Station		
	Willowbank Fire Station	Mosgiel Fire Station	Kaikorai Police Station		
	Mosgiel Fire Station	Wakari Rural Fire Station			
	Waitati Fire Station	Dunedin Central Fire Station			
	Dunedin Central Fire Station	Outram Fire Station			
	Outram Fire Station	Port Chalmers Fire Station			
	Dunedin Central Police Station & Southern Police District HQ	St Kilda Fire Station			
	Dunedin North Police Station	Waitati Fire Station			
	Mosgiel Police Station	Ravensbourne Fire Station			
		Dunedin Central Police Station & Southern Police District HQ			
		Dunedin South Police Station			
		Mosgiel Police Station			
Queenstown Lakes	Luggate Fire Station	Wanaka Fire Station	Lake Hawea Fire Station	Wanaka Fire Station	Queenstown Police Station
		Queenstown Fire Station		Wanaka Police Station	
		Queenstown Police Station			
		Wanaka Police Station			

	Hazard type				
District	**River and lake flooding**	**Liquefaction**	**Active Faults**	**Landslide**	**Alluvial fan**
Central Otago	Alexandra Police Station CODC Central Otago District EOC	Omakau Fire Station Omakau Police Station	Roxburgh Fire Station Clyde Fire Station Roxburgh Police Station Alexandra Police Station CODC Central Otago District EOC		
Clutha	St John Ambulance Lawrence St John Ambulance Balclutha St John Ambulance Milton Milton Fire Station Balclutha Fire Station Lawrence Fire Station Kaitangata Fire Station Waitahuna Fire Station Lawrence Police Station Balclutha Police Station	St John Ambulance Lawrence St John Ambulance Balclutha St John Ambulance Milton Heriot Fire Station Milton Fire Station Kaitangata Fire Station Waitahuna Fire Station Owaka Fire Station Balclutha Fire Station Lawrence Fire Station Lawrence Police Station Milton Police Station Owaka Police Station Balclutha Police Station	Waitahuna Fire Station		
Waitaki		Palmerston Police Station Oamaru Police Station WDC EOC			Palmerston Police Station

9.5 Appendix E. Natural Hazards Exposure Assessment Methodology

MEMORANDUM

To:	**Tim van Woerden and Natural Hazards Team**
From:	**Andrew Welsh**
Date:	**14/03/2025**
Re:	**Otago Natural Hazards Exposure Assessment – Exposure assessment methodology**

1.0 Background

The ORC is undertaking a natural hazard exposure and risk assessment work programme, designed as a review and high-level assessment of natural hazard exposure and risks for mapped natural hazards in the Otago region. The purpose of the natural hazards exposure and risk assessment (NHERA) is to work towards a comprehensive, regional-scale, spatial understanding of Otago's natural hazards exposure and risks.

The proposed natural hazard exposure assessment programme is listed in the 2024-2034 ORC Long-term Plan (LTP) as work to "Develop comprehensive risk mapping of natural hazards across Otago" and specifies the performance measure: "Complete regional natural hazards risk assessment (NHERA) and develop a regional approach for prioritising adaptation to inform adaptation planning and implementation" (ORC, 2024). In addition, the work programme aims to support the ORC community outcome "Communities that are resilient in the face of natural hazards & climate change and other risks." Further detail on the programme background is outlined in an ORC committee paper by van Woerden *et al* (2023).

The work will look at all regionally mapped natural hazards datasets for the full Otago region and hence will not include those from more detailed, site-specific studies (e.g. Glenorchy liquefaction vulnerability mapping).

This memorandum will cover the general methodology used in the exposure analysis phase of the Otago Natural Hazards Exposure and Risk Assessment. Please refer to the technical report van Woerden and Welsh (2025) for a full description and overview of the Otago Natural Hazards Exposure and Risk Assessment.

2.0 Approach

2.1 Proposed Otago RPS (2021) and NHRA framework

The proposed Otago Regional Policy Statement 2021 (pORPS) has been used as the basis for the NHERA exposure analysis framework (ORC, 2021). The pORPS event consequence table (Table 1) incorporates five different risk elements, these being 1) social/culturally significant buildings, 2) buildings, 3) critical facility buildings, 4) lifelines infrastructure (undifferentiated) and 5) health and safety (people injured or dead).

Table E1: Proposed Otago Regional Policy Statement (pORPS) event consequence table

Severity of Impact	**Built**				**Health & Safety**
	Social/Cultural	*Buildings*	Critical *Buildings*	Lifelines	
Catastrophic (V)	≥25% of *buildings* of social/cultural significance within hazard zone have functionality compromised	≥50% of affected *buildings* within hazard zone have functionality compromised	≥25% of critical facilities within hazard zone have functionality compromised	Out of service for > 1 month (affecting ≥20% of the town/city population) OR suburbs out of service for > 6 months (affecting < 20% of the town/city population)	> 101 dead and/or > 1001 injured
Major (IV)	11-24% of *buildings* of social/cultural significance within hazard zone have functionality compromised	21-49% of *buildings* within hazard zone have functionality compromised	11-24% of *buildings* within hazard zone have functionality compromised	Out of service for 1 week – 1 month (affecting ≥20% of the town/city population) OR suburbs out of service for 6 weeks to 6 months (affecting < 20% of the town/city population)	11 – 100 dead and/or 101 – 1000 injured
Moderate (III)	6-10% of *buildings* of social/cultural significance within hazard zone have functionality compromised	11-20% of *buildings* within hazard zone have functionality compromised	6-10% of *buildings* within hazard zone have functionality compromised	Out of service for 1 day to 1 week (affecting ≥20% of the town/city population) OR suburbs out of service for 1 week to 6 weeks (affecting < 20% of the town/city population)	2 – 20 dead and/or 11 – 100 injured
Minor (II)	1-5% of *buildings* of social/cultural significance within hazard zone have functionality compromised	2-10% of *buildings* within hazard zone have functionality compromised	1-5% of *buildings* within hazard zone have functionality compromised	Out of service for 2 hours to 1 day (affecting ≥20% of the town/city population) OR suburbs out of service for 1 day to 1 week (affecting < 20% of the town/city population	1 dead and/or 1 – 10 injured
Insignificant (I)	No *buildings* of social/cultural significance within hazard zone have functionality compromised	< 1% of affected *buildings* within hazard zone have functionality compromised	No damage within hazard zone, fully functional	Out of service for up to 2 hours (affecting ≥20% of the town/city population) OR suburbs out of service for up to 1 day (affecting < 20% of the town/city population	No dead No injured

When assessing consequences within this matrix, the final level of impact is assessed on the 'first past the post' principle, in that the consequence with the highest severity of impact applies. For example, if a *natural hazard* event resulted in moderate severity of impact across all of the categories, with the exception of critical *buildings* which had a 'major' severity of impact, the major impact is what the proposal would be assessed on. If a *natural hazard* event resulted in all of the consequences being at the same level (for example, all of the consequences are rated moderate), then the level of consequence is considered to be moderate.

When this assessment is being undertaken in accordance with HAZ-NH-M3(7)(a) or HAZ-NH-M4(7)(a) the text within Step 2 shall guide the assessment of *natural hazard* consequence.

The NHERA focuses on 3 of these (buildings, critical facilities and health and safety, Table 2).

Buildings provide a direct measure of building infrastructure exposed to a hazard. They can also be used to estimate usual resident population affected where building type information is available separating dwellings from other types of buildings.

Critical Community Facilities (CCF) provide a direct measure of emergency services and disaster operation/coordination centres exposed to a hazard. They are an important indicator of social/community disruption in a hazard event in the case where critical facilities and associated services are significantly affected and/or not available due to hazard occurrence.

The **health and safety** element provides a measure of the ***usual resident population*** estimated to be exposed to a hazard. This is a primary indicator of social/community disruption in the event of hazard occurrence.

Table E2: oRPS principles-based **exposure** table

Exposure level	**Built**		**Health and Safety**
	Buildings	**Critical Community Facilities (CCF)**	**Usual resident population**
Very high (V)	≥ 50% of buildings within **community area** are located within a mapped hazard area	≥ 25% of CCF buildings within **community area** are located within a mapped hazard area	> 100 within **community area** are located within a mapped hazard area
High (IV)	21-49% of buildings within **community area** are located within a mapped hazard area	11-24% of CCF buildings within **community area** are located within a mapped hazard area	11-100 within **community area** are located within a mapped hazard area
Moderate (III)	11-20% of buildings within **community area** are located within a mapped hazard area	6-10% of CCF buildings within **community area** are located within a mapped hazard area	2-10 within **community area** are located within a mapped hazard area
Low (II)	2-10% of buildings within **community area** are located within a mapped hazard area	1-5% of CCF buildings within **community area** are located within a mapped hazard area	1 within **community area** are located within a mapped hazard area
Very low (I)	≤ 1% of buildings within **community area** are located within a mapped hazard area	No CCF buildings within the **community area** located within a mapped hazard area	None within **community area** are located within a mapped hazard area

Lifelines infrastructure is not considered in the NHRA. This is to avoid overlap and/or any duplication of CDEM lifelines work; and instead to complement any existing or future CDEM work in this area. The social/cultural buildings element is also not considered in the assessment. At the time of writing, no consistent and comprehensive dataset compiling all social/cultural buildings in Otago is available.

The three elements chosen (buildings, critical facilities, health and safety (estimated usual resident population) are considered more appropriate for the NHERA as together they provide a holistic overview of hazard consequences and social impact at community scale. Further, the lifelines infrastructure and social/culturally significant buildings elements would likely add more value and be more appropriate for analysis at a more detailed scale than that chosen for this phase of the NHERA (i.e. as part of the subsequent risk assessment and prioritisation phase of the natural hazards exposure and risk assessment).

2.2 Exposure

Mapped natural hazard extent is consistent across datasets used in the analysis and hence this is the primary means to calculate exposure (Table 2).

The level of exposure for a community area is assessed on the 'first past the post' principle, in that the highest level of exposure across the three categories applies. For example, if a natural hazard event resulted in moderate exposure level across all the categories for a community area, with the exception of critical facility buildings which is classed as 'high', that community area will be classed with a high exposure level. If a natural hazard event resulted in all of the measures being at the same level (for example, all of the elements are classed moderate), then the level of exposure will be classed as moderate.

3.0 Modelling platform, data sources and datasets

Exposure analysis was completed using the RiskScape modeling platform, an open-source software with a flexible modelling engine for multi-hazard risk analysis (Paulik *et al*, 2022). Riskscape provides a highly customizable and efficient modelling environment, allowing the user to tailor the input data and run an automated series of linked processes to produce results and reporting outputs quickly (Riskscape, 2025). A detailed description of the data sources and datasets used in the analysis is provided below.

3.1 Natural hazard datasets

The natural hazard datasets used in the NHERA analysis are listed in Table 3 below. These are all 5m cell size spatial resolution raster datasets. These datasets were originally represented as polygon features. To enhance the efficiency of the riskscape modelling process, the polygon datasets were converted to raster data structures and a 5m cell size was chosen as the best compromise between mapped feature accuracy and riskscape model efficiency.

Natural hazard exposure analysis was completed for those datasets with mapping coverage across the full Otago region. Exposure analysis was also completed for coastal erosion in the Waitaki district as this information was available for the whole coastline in the district (Bosserelle et al, 2019), but not for other areas along the Otago coast due to incomplete coverage. Seismic ground shaking (potentially outdated information) datasets were not included in this phase of the analysis.

Table E3: Natural hazard datasets used in the exposure analysis

Hazard Type	Hazard Mapping Dataset
River and Lake Flooding	River and lake flooding
	Active alluvial fans (stream flood-dominated)
Seismic	Active Faults
	Liquefaction
Slope Stability	Landslide
	Rockfall
	Active alluvial fans (debris & composite)
Coastal Erosion and Inundation	Storm surge inundation
	Coastal erosion (Waitaki only)
	Tsunami inundation

3.2 Dataset refinements

Some refinements and adjustments were made to datasets for the analysis. Features in the ORC Alluvial Fans Otago regional dataset were restricted to just those recorded as 'active' in the fan activity field within the layers metadata. For the analysis, active alluvial fans are argued to pose a more significant natural hazard threat compared to those recorded as inactive, because fan forming processes are interpreted to be ongoing and/or there is potential for significant reactivation during extreme events (e.g. heavy rainfall, earthquake) (Barrell, 2015).

In addition, alluvial fans classified as 'active floodwater-dominated' were added to the regional Otago flood hazard dataset to create a new version of the Otago Flood Hazard dataset. This was done because 1) in some cases these features were already represented in this layer and 2) they represent the flood hazard component from small tributaries and steep streams on alluvial fans, being in essence a flood water hazard extent.

A new version of the alluvial fan dataset was then created comprising active alluvial fans with a debris component or a combination of processes. In particular, the remaining alluvial fan hazard extents represent the other predominant hazards - debris dominated and composite (combination of concurrent processes) phenomena. The likelihood for significant hazard occurrences is generally understood to be in the vicinity of hundreds of years, in contrast to flood water events which are expected to be more frequent (tens to hundreds of years recurrence) (Barrell, 2015). Hence the flood water hazard on alluvial fans is grouped with the Otago Flood Hazard layer as it interpreted to be better represented in this dataset for the current analysis.

In addition, the river flooding layer from the general coastal hazard mapping dataset (ORC, 2014-2), refined mapping for Dunedin's Urban Streams (ORC, 2014-1) and mapping of the flood hazard for the Milton urban area (ORC, 2012) were also added to the Otago Flood Hazard dataset to ensure full coverage of mapped river and lake flood hazard extents for the region.

To determine exposure of elements to Active faults in the region, buffer polygons were produced for each trace. A 250m buffer distance was chosen for each fault trace (line feature) representing the margin of uncertainty around the mapping of active fault traces (Barrell, 2016, Barrell, 2019, Barrell, 2021).

Buffer polygons were also created for the line features in the Waitaki Coastal Erosion dataset. A 400m distance was chosen, extending coastwards from each mapped coastal hazard zone (CHZ) line feature. This ensured all land between the mapped CHZ lines and the coastal margin (LINZ, 2023) was captured for the exposure analysis.

3.3 Location unit, building and critical facility datasets.

A number of geographic location unit polygon datasets were acquired from Statistics New Zealand (Stats NZ, 2023) for the exposure analysis (Table 4). These were used to establish a consistent geographic framework of location units at appropriate scales (community, district, regional) for the analysis. The urban-rural boundaries dataset allows distinction between built up areas (urban areas - rural settlements) and the rural areas outside these population centres (Figure 1).

Statistical Area 1 and 2 datasets were used to define community boundaries for urban areas and rural settlements, and the remaining rural areas outside of the urban area-rural settlement boundaries. Statistical area 2 (SA2) is designed to represent communities that interact socially and economically (Stats NZ, 2023). In urban areas, they are equivalent to suburbs. Statistical area 1's (SA1) are subsets of these SA2 areas and represent smaller community units that make up the wider SA2 community.

Urban areas and rural settlements in the region are generally defined by SA2's, with some smaller settlements defined by SA1. Rural Otago areas outside of these settlements are defined by SA1's. This ensures the rural units are 1) an appropriate size and scale for analysis in comparison to the urban area rural settlement units, and 2) are more appropriate for the proposed community prioritisation framework (please refer to Woerden et al, 2023 for more information on the proposed community prioritisation framework).

Figure E1: Spatial location of urban areas and rural settlements (blue) and rural Otago community units (yellow).

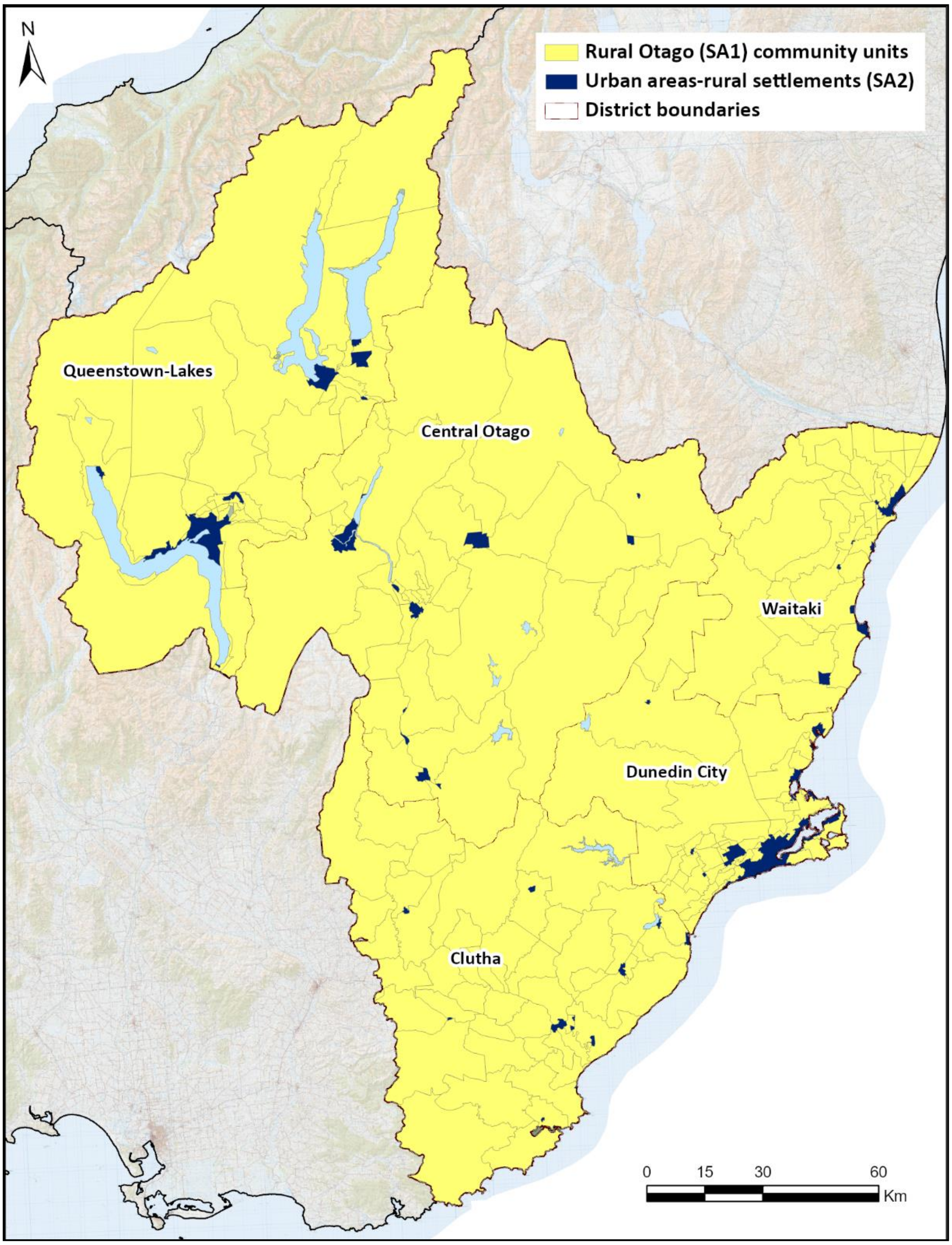

Table E4: Location unit, building and critical facility datasets

Datasets used:	**Source:**
2023 Statistical Area 1 boundaries (SA1)	Statistics NZ: Data Finder website
2023 Statistical Area 2 boundaries (SA2)	Statistics NZ: Data Finder website
2023 Urban Rural classification boundaries	Statistics NZ: Data Finder website
2023 Census Usual Resident Population counts	Statistics NZ: 2023 census-statsnz hub website
2023 District and Regional Council Boundaries	Statistics NZ: Data Finder website
2024 NZ Building Inventory dataset	GNS Science – Finn Scheele
2023 Critical Community facilities	Otago Civil Defence and Emergency Management (OCDEM), modified and updated by ORC Natural Hazards

NZ census 2023 usual resident population count data for all SA1 and SA2 units in the region was acquired from the Statistics NZ: 2023 census-statsnz hub website (Stats NZ, 2025-2). District and regional council boundaries were also acquired from Statistics NZ (Stats NZ, 2025-1). These were used to calculate statistics at district and regional scale and compliment the information at SA1 and SA2 community level, allowing a holistic overview of natural hazard exposure at different scales in Otago.

The GNS NZ Building Inventory and Critical Community Facility datasets comprised the source data to represent 'elements at risk' for the exposure analysis. The GNS NZ Building Inventory dataset (polygon geometry) was developed using the latest (2024) LINZ NZ Building Outline and LINZ Primary Parcels datasets, available from the LINZ Data Service, in combination with property data acquired from Corelogic (Scheele et al, 2023).

The Critical Community Facilities (CCF) layer was originally acquired from Otago CDEM as a point location dataset. This layer was then converted to a polygon building location outline dataset to ensure it was up to date and facilitate the analysis. It comprises all emergency services and disaster operation/coordination centres across the region.

4.0 Workflows

Exposure analyses for the Otago Natural Hazards Exposure Assessment were carried out using the latest version of NIWA Riskscape software 1.8.0.

ESRI ArcGIS Pro 3.3.1 (2025) software, imagery datasets (ESRI 2023 basemaps, google earth, street view imagery) were also used to cross reference and visualise map information. A description of the workflows undertaken to determine exposure statistics and mapping outputs is presented below.

4.1 Initial base data workflow:

The **Critical Community Facilities** dataset acquired from Otago CDEM (2022) is a point geometry feature layer (called Critical Community Sites) with locations identified as points on or close to the relevant site of interest. To ensure all critical site building locations were included partly or fully within polygon boundaries for location units and natural hazard mapped layer extents, the point dataset was converted into polygon geometry. This was done by cross referencing point locations with the latest google earth and street view imagery, and then using the GNS NZ Building Inventory dataset to determine the outline extents of those building locations. Disaster operation/coordination centre locations were also located and added to the dataset at this stage. Polygon features were then created for all point locations using the NZ Building Inventory outline features for each location of interest.

The Critical Community Sites polygon layer displays all building site locations (emergency response facilities and coordination centres) across Otago. In this case, some facilities (e.g. Dunedin Wakari Hospital) are made up of multiple buildings. To ensure critical community sites were grouped by facility, two new fields (Site count and Facility) were added to the

Critical Community Sites polygon layer. The feature layer was then renamed Critical Community Facilities and the facility count used in the analysis to reduce skew in the resulting outputs (i.e. normalise across the dataset to ensure e.g. Wakari Hospital (30 buildings) is not over-represented in the results when comparing with other sites across the region, which may only have 1 building but are considered equally as critical to the community they service during an event).

2023 **Statistical Area 1** (SA1) and **Statistical Area 2** (SA2) polygon datasets and the **Urban Rural** Classification boundaries dataset were acquired from the Stats NZ data finder website. The Urban-Rural boundaries dataset was then used to identify 1) all SA's classified as either urban area or rural settlement, and 2) all SA1's outside out the urban area-rural settlement boundaries (Figure 1).

Two new polygon feature class datasets were then established for the analysis:

- ***Urban areas and rural settlements***; and
- ***Rural areas outside of urban area-rural settlements***

For the two new base datasets, a field for total usual resident population count was added and populated with official 2023 usual resident population count census data acquired from Stats NZ (Stats NZ, 2025-2).

These were then combined into one polygon dataset comprising all SA features:

- **SetRural**

In addition, resident information for rest homes in Otago was acquired from the Ministry of Health website (MoH, 2023). The NZ Building Inventory was updated with this information and subsequently used to calculate an adjusted UR population stat (essentially UR population excluding those who live in rest homes – please refer to section 4.2.4 for a detailed explanation of this process). This information is stored in a new attribute field created in the SetRural layer called 'Adjusted UR Population'. This completed preparation of the area layer dataset input for the riskscape model.

4.2 Riskscape Exposure Model

A model was built in Riskscape to classify all community areas (defined by Statistical Areas (SAs)) within the region by level of exposure associated with the mapped natural hazards chosen for the analysis (Table 3). The Riskscape model pipeline (series of data-processing steps) is shown in Figure 2 below (next page) and is followed by a detailed breakdown of each processing phase in the model.

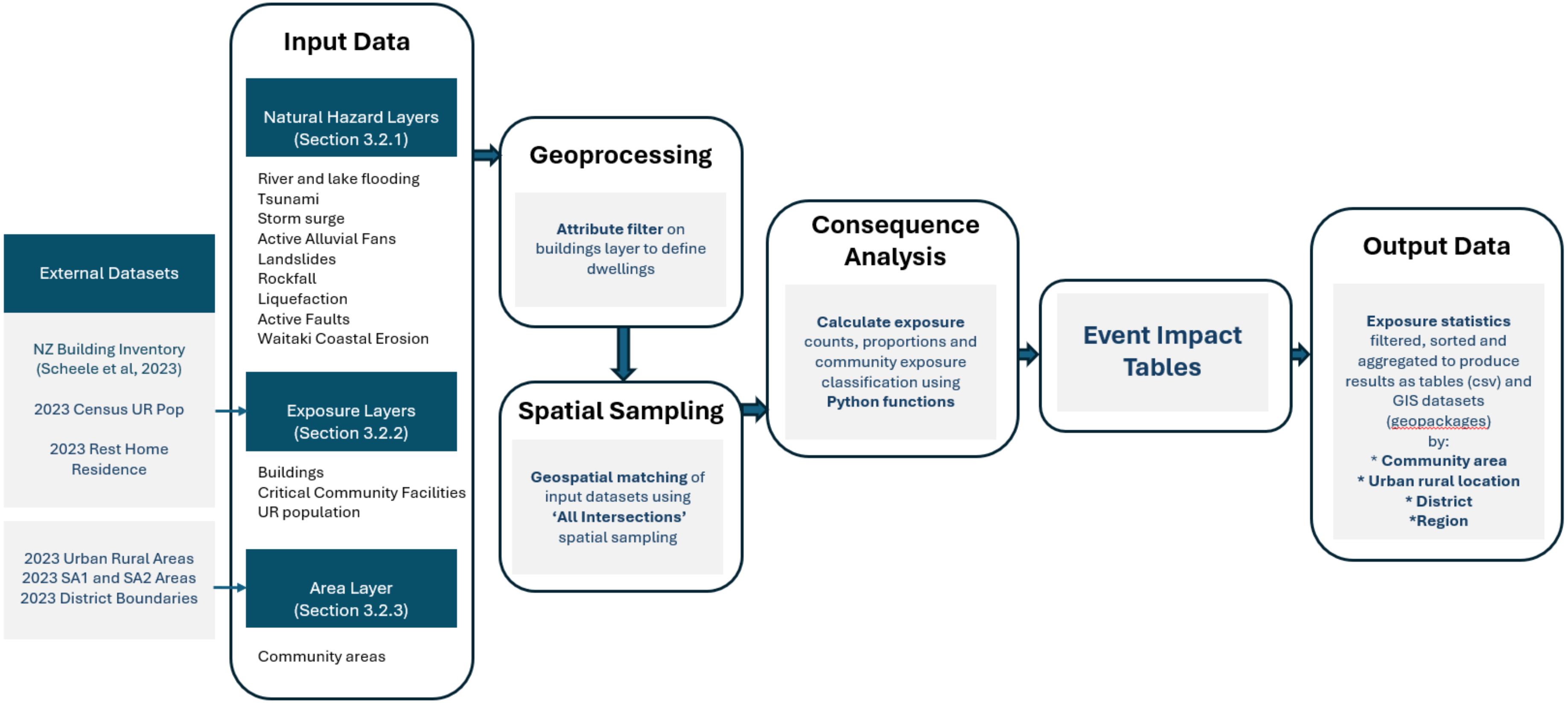

Figure E2: Generalised Riskscape model pipeline for the exposure analysis

4.2.1. Input data

The main data inputs to the model are listed below:

Exposure data (elements at risk source datasets):

- The GNS NZ Building Inventory (building outlines polygon dataset).
- Critical Community Facilities (building outlines polygon dataset).
- Usual resident (UR) population (census 2023 by statistical area), incorporated into the area data layer used for the analysis.
- Rest home residence – facility total bed counts and average occupancy (MoH, 2023).

Hazard data:

- Raster layer datasets with a 5m cell size spatial resolution:
  - River and lake flooding
  - Active Alluvial Fans
  - Landslides
  - Rockfall
  - Active Faults
  - Liquefaction awareness areas
  - Storm surge
  - Tsunami
  - Waitaki Coastal Erosion:
    - CHZ 50, 50 year outlook
    - CHZ 50, 100 year outlook
    - CHZ 95, 50 year outlook
    - CHZ 95, 100 year outlook

Area data:

- 'SetRural' layer - Polygon dataset for statistical area-defined community areas in Otago, combining urban areas and rural settlements, and rural areas outside of these (Rural Otago). These areas aggregate to form district boundaries, allowing analysis at community, urban-rural location, district and regional scales.

4.2.2. Geoprocessing (pre-processing).

This phase is skipped for the calculation of buildings and Critical Community Facilities exposed i.e. no additional pre-processing to filter or transform the input geometry is undertaken on the input datasets.

For the calculation of UR population exposed, an attribute filter is used to select specific building types in the NZ Building Inventory dataset to approximate the spatial distribution of UR population in the region. This is described in detail in section 4.2.4.

4.2.3. Spatial sampling phase

To begin, join steps are run to combine input datasets and prepare the output for spatial sampling. Fields from the building and CCF datasets are joined to the area layer data.

The next stage involves geometry-based lookup sampling, whereby coverages (grid-based GeoTiff raster files) are created for the spatial matching of the input exposure and hazard datasets.

Riskscape geospatially matches the building and CCF building footprint locations with each hazard-layer coverage, returning a hazard intensity measure for that building, in this case whether it intersects the hazard layer or otherwise.

In particular, the 'is-exposed' in built Riskscape Function is run to count the building and CCF features that are exposed to the hazard within each community area, based on 'all intersections' spatial sampling i.e. if any of the building footprint is exposed it will be counted as exposed. The outputs are counts for all buildings and CCFs that intersect natural hazard areas in each community area. The results of the analysis are then saved as building impact tables (csv format) for each of the building and CCF risk elements.

4.2.4. Consequence analysis

The counts of building and CCF features determined to be exposed to the hazard are then calculated as a percentage of the total building and CCF features within that community area.

The calculated proportions are classified in accordance with the exposure table (Table 2) and every community unit is assigned a number corresponding to the level of exposure from (V) Very High to (I) Very Low) to each natural hazard.

Three separate python functions were developed to reflect the categories in the exposure table (Table 2) and used in the Riskscape model to classify community area units by exposure level:

- blbbuckets – calculates **building exposure** level for each community area
- ccfbuckets – calculates **critical community facility exposure** level for each community area

- popbuckets – calculates estimated **usual resident population exposure** level for each community area

<u>Usual resident (UR) population exposed estimate</u>

To determine an estimate for the usual resident population exposed, 3 main datasets are used as inputs:

- the NZ Building Inventory dataset;
- Resident information for all rest homes in Otago acquired from the MoH (2023) website; and
- 2023 NZ Census usual resident (UR) counts for each community area, within the SetRural dataset

The NZ Building Inventory includes the field attribute 'use category' which classifies buildings by their type of use. This field attribute is used in the analysis to define the building types which represent a main place of residence for the UR population (i.e. where they sleep and generally live). In particular, the 'residential dwelling', 'lifestyle' and 'rest home' categories are chosen to represent dwellings, and hence approximate the spatial distribution of UR population for community areas in Otago.

In addition, a third category was created in the building inventory 'farm/rural dwelling' to represent dwellings in rural areas. The process for this is described below and shown graphically in Figure 3.

<u>Addition of Farm/rural dwelling use category attribute</u>

In many rural locations, building features have been assigned an 'unknown' use category attribute within the building inventory. It is expected a certain number of these will be dwellings (primary place of residence). Overall, buildings likely to be dwellings are not well defined in rural areas due to incomplete or absent property information in the source Corelogic dataset used to build the building inventory (Scheele et al, 2023).

To improve the classification of dwellings in rural areas, those locations containing a large number of buildings with an 'unknown' use category (e.g. rural Waitaki District) were examined manually using the latest aerial and satellite imagery available through ESRI, along with supplementary data sources such as existing photographs and google street view (where available). Following visual on-screen inspection of rural buildings in the dataset, some specific criteria (Table 5) were developed to distinguish general rural farm type buildings (sheds, barns, garages, storage etc.) from those that could be considered dwellings: Buildings >65m2 in close proximity to a main drive-way (within approx. 5m), with more complex roof and footprint characteristics (e.g. multiple pitched roof parts (more than 2), chimney structures, adjoining decks) and/or with other evidence consistent with a dwelling (e.g. vehicles parked next to them, visible bikes, trampolines close by). Those meeting the four primary indicators shown in Table 5, were interpreted to be farm/rural type dwellings.

A new use category attribute (farm/rural dwelling) was then created in the NZ building inventory and assigned to those buildings interpreted to be dwellings, with the aim of better approximating the spatial distribution of UR population in rural areas, and hence reducing the potential of an undercount of UR population exposed to hazards for these areas.

Table E5: Criteria used to identify dwellings in rural areas of Otago

Rural/Farm Dwellings: Primary indicators	Rural Farm Dwellings: Secondary indicators	Non-dwelling buildings
Building footprint >65m2	Vehicles parked beside house	Building footprint <65m2
Drive way next to house (<=5m away)	Other evidence of residence (bikes, trampolines nearby)	No drive way next to house; > 5m away
Complex roof characteristics (multiple (>2) pitched roof segments); lower reflective properties (e.g. colours other than white, cream)		Basic roof structure (<= 1 pitch segments); Higher reflective properties (e.g. white, cream spectral signature
Other distinctive building characteristics (Chimney structures, adjoining decks)		No chimney, and/or adjoining deck structures

<u>Dwellings in the analysis</u>

Following the addition of the 'farm/rural dwelling' use category to the NZ Building Inventory dataset, 4 building use category types are confirmed to represent dwellings in the analysis:

- Residential dwelling,
- Lifestyle
- Farm/rural dwelling, and
- Rest home

Only buildings with a floor area greater than or equal to 65m^2 are selected. This is based on the assumption that buildings with a floor area smaller than 65m^2 are more likely to be sheds, garages or other farm type buildings rather than dwellings which house the UR population.

Of the 4 building use category types above, residential dwelling, lifestyle and farm/rural dwelling are used to represent 'standard' dwellings, while rest homes are considered separately (please see rest home use category below). A total count of 'standard' dwellings is then calculated for each community area.

Rest home use category

Rest home dwellings (RH) are considered separately from the other dwelling types for the estimate of population as they often contain a large amount of people residing in one location. Information on rest home bed counts and occupancy is readily available for facilities in Otago via the Ministry of Health and Aged Residential Care websites (MoH, 2023; ARC, 2024). Using these resources, the spatial location for all rest homes in Otago was determined, and total bed counts (which indicate maximum available occupancy) were acquired for each facility (MoH, 2023). The NZ Building Inventory source dataset was then updated to include 3 new attribute fields incorporating this information:

- RH facility total bed count (acquired from MoH, 2023)
- RH facility building count (footprint determined by cross referencing building inventory with imagery)
- RH facility average beds per building (calculated as below)

RH facility average beds per building:

For rest home facilities that have more than one building, the acquired bed count is divided amongst the number of buildings for that facility to give an **average bed count per building.**
e.g. Bed count 108 and 10 buildings = average bed count of 10.8 beds per building.

This is done to ensure an approximate bed count is available per building for each rest home facility.

RH beds aggregate per community area:

This is then aggregated (sum) for each community area to give the total number of **RH beds per community area.**

Convert to estimate of population:

Next, an estimate for the UR population in rest homes is calculated using the RH facility bed count information and average occupancy of rest homes in Otago (2023) acquired from the Aged Residential Care Sector Report (ARC, 2024) as primary inputs. According to ARC (2024), the average occupancy of rest homes in Otago in 2023 was 87%.

This figure (87%) is used to convert the **RH beds per community area** result into an estimate of population residing in rest homes for that community area:

RH Beds per community area * 0.87 =

Estimate for **total UR Population residing in rest homes** per community area.

Calculation of UR population residing in 'standard' dwellings

Buildings with use categories: residential dwelling, lifestyle and farm/rural dwelling are used to define 'standard' dwellings i.e. those other than rest homes.

For each community area, the count for total **UR population residing in rest homes** is subtracted from the total **UR population census count** to produce a stat called 'Adjusted UR population':

Total UR population residing in rest homes **–**

Total UR population census count

= **Adjusted UR population count.**

The 'adjusted UR population' count represents the UR population in the area excluding those who live in rest homes.

The total UR population census count is hence partitioned into 2 parts for the analysis which together make up the total UR population census count for that community area:

Total UR population in rest homes +

Adjusted UR population count

= **Total UR population census count**

The adjusted UR population count for each community area is then divided over the total 'standard' dwelling count for that community area to give an **average UR population per 'standard' dwelling** metric:

Adjusted UR population census count / total 'standard' dwelling count

= Average UR population per 'standard' dwelling

Total UR population exposed for community areas

To determine the total number of UR population exposed to natural hazards for all community areas in Otago, processes are run in Riskscape to determine the total number of 1) dwellings and 2) rest home beds located **within natural hazard extents.**

First, a count of all standard dwellings located within the natural hazard area is determined. This is then multiplied by the average UR population per 'standard' dwelling stat to give the 'total number of UR population exposed to the hazard for **'standard dwellings.'**

In addition, a count of all rest home beds within the hazard extent is determined (using the RH beds per building stat within the NZ Building Inventory). This number is then multiplied by 0.87 to give an estimate of the 'total number of UR population **exposed in RHs'** for each community area.

These two are added together to give the **total number of UR population exposed** to the hazard for each community area:

Total UR pop exposed in RH +

Total UR pop exposed in 'standard' dwellings

= **Total UR population exposed to the hazard** for a community area

Essentially the sum of population exposed in rest homes and the sum of population exposed in all other dwellings ('standard' dwellings) are added together to find the total population exposed to a natural hazard for each community area.

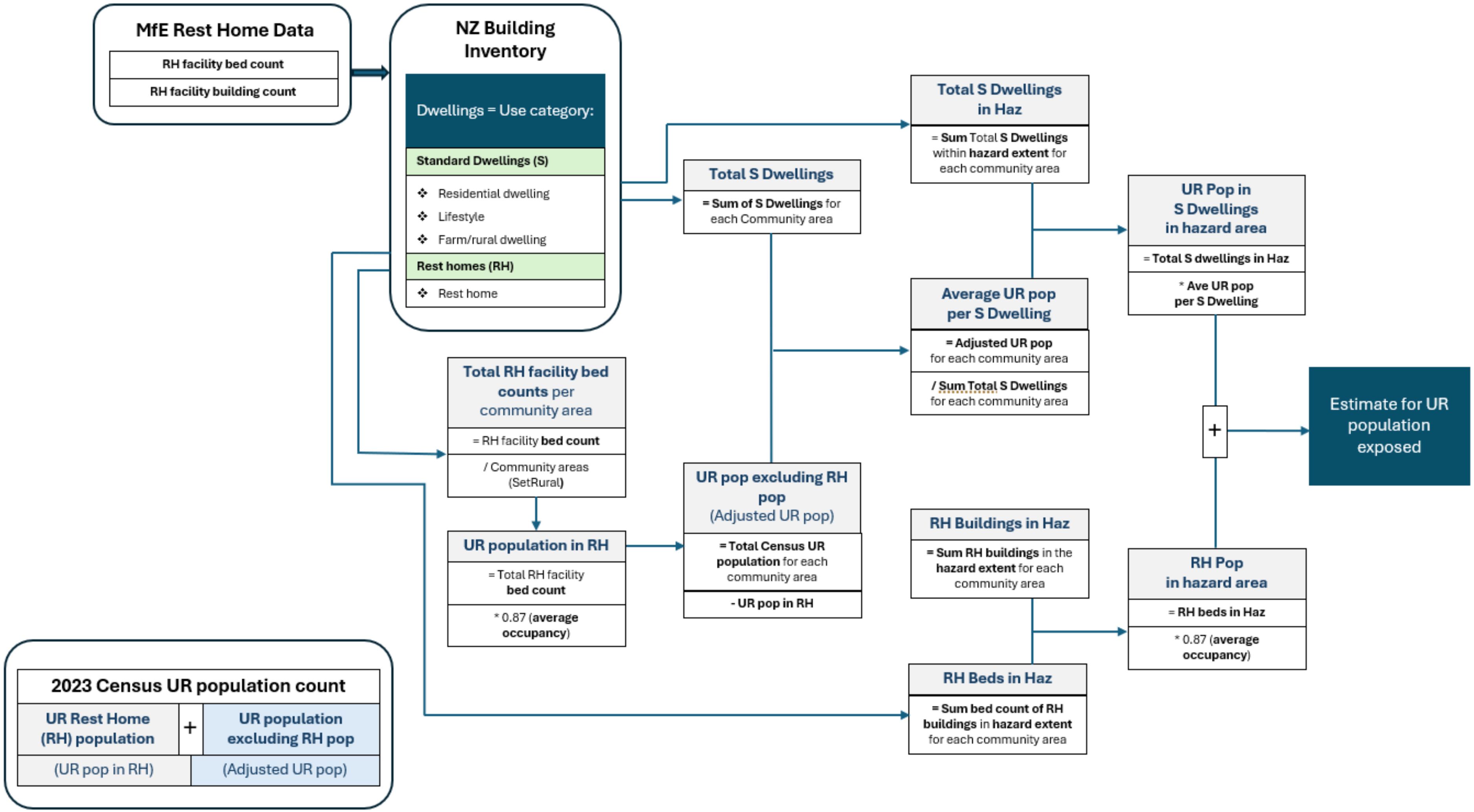

Figure E3: Overview of the process for the UR population exposed estimate.

4.2.5. Reporting

Event impact tables are produced during the consequence analysis phase displaying exposure statistics at community area level, including the exposure level classification for each community area, counts of communities for each exposure level, and regional statistics for the counts and proportions of elements-at-risk. These results are then filtered, aggregated and sorted before being saved to file as Microsoft exel csv's, and/or geopackages.

District exposure outputs

For all community areas, exposure statistics are aggregated by district. The filter function is used save individual tables for each natural hazard and the sort function is used to sort alphabetically by district. The resulting tables are saved as Microsoft Excel csv spreadsheets.

Urban area or rural settlement outputs

Exposure statistics are aggregated for each urban area or rural settlement location. The filter function is used to screen for urban areas and rural settlements only and then save individual tables for each natural hazard. The sort function is used to sort by population count. The resulting tables are saved as Microsoft Excel csv spreadsheets.

Rural Otago areas outputs

Exposure statistics for rural Otago areas are aggregated by district for each rural community area. The filter function is used to screen for rural Otago areas only and then save individual tables for each natural hazard. The sort function is used to sort by population count. The resulting tables are saved as Microsoft Excel csv spreadsheets.

Full exposure analysis results are saved for each natural hazard and the source area layer (SetRural, which contains fields for all interim calculated counts and proportions) in geopackage file format.

Additional specific outputs e.g. Top 10 communities exposed for each hazard at each scale (community, urban area or rural settlement, district, region etc) are determined by running filtering options on the full exposure results in Microsoft Excel. A list of some of the main outputs from the model is shown below:

Main model outputs:

- Exposure table compiling the event impact exposure information for all hazards by **district**; and
    - Separate individual exposure tables for each hazard by **district** (csv format).

- Exposure table compiling the event impact exposure information for all hazards by **urban area or rural settlement**; and
    - Separate individual exposure tables for each hazard by **urban area or rural settlement location** (csv format).
- Exposure table compiling the event impact exposure information for all hazards by **district** for **rural Otago areas**; and
    - Separate individual exposure tables for each hazard by district for **rural Otago areas** (csv format).
- Exposure table showing counts and proportions of exposure elements and community area sum total counts **for each natural hazard type** in the **region** (csv format).
- SetRural area layer feature class (geopackage format).
- Exposure table output for all hazards; and individual exposure table outputs for each hazard (geopackage format).

5.0 Example Outputs

Selected examples of the exposure results generated in the analysis are displayed as tables from the next page below. Further table output examples for the analysis are presented in the van Woerden and Welsh (2025) technical report.

5.1 Exposure table examples

Table E6: Exposure by **natural hazard type** for Otago, with total counts and proportions for population, buildings and critical facilities, and count of communities classified with high or very high exposure.

Hazard Type	Population (count)	Population (%)	Buildings (count)	Buildings (%)	Critical Community Facilities (CCF)	CCF (%)	Communities with high or very high exposure
River and lake flooding	38778	16.1	33,898	16.1	23	25.6	159
Liquefaction	45,047	19.1	43,029	20.4	37	41.1	146
Active Faults - Otago	21,949	9.1	20,096	9.5	10	11.1	108
Landslide	8,038	3.3	6,592	3.1	3	3.3	61
Alluvial fan (debris inundation)	5,473	2.3	5,904	2.8	3	3.3	51
Rockfall	1,234	0.5	1,056	0.5	0	0.0	18
Coastal inundation - Tsunami	504	0.2	1,130	0.5	0	0.0	13
Coastal inundation – Storm surge	504	0.2	1,122	0.5	0	0.0	11
Waitaki Coastal Erosion - CHZ 95, 100 yr outlook	37	0.0	111	0.1	0	0.0	1
Waitaki Coastal Erosion - CHZ 95, 50 yr outlook	24	0.0	69	0.0	0	0.0	1
Waitaki Coastal Erosion - CHZ 50, 100 yr outlook	19	0.0	57	0.0	0	0.0	0
Waitaki Coastal Erosion - CHZ 50, 50 yr outlook	5	0.0	36	0.0	0	0.0	0

Table E7: River and lake flood hazard exposure at **district scale**, ordered by population count and listing total count of communities with a high to very high exposure.

District	Communities with high or very high exposure	Population (count)	Population (% of District)	Buildings (count)	Buildings (% of District)	Critical Community Facilities (CCF)
Dunedin City	62	27,969	21.7	19,683	21.9	10
Clutha District	33	3,754	20.2	5,593	18.7	10
Queenstown-Lakes	18	2,883	6	3,161	8.7	1
Waitaki	14	2,707	12.5	2,870	11.2	0
Central Otago	32	1,466	6	2,591	9	2
Otago Total	**159**	**38,778**	**16.1**	**33,898**	**16.1**	**23**

Table E8: Flood hazard exposure for **urban areas - rural settlements** and the communities within them: **Top 10** urban area- rural settlements ordered by population count.

Location	District	Communities with high or very high exposure	Population (count)	Population (% of location)	Buildings (count)	Buildings (% of location)	Critical Community Facilities (CCF)
Mosgiel	Dunedin City	6	12,530	85.9	8,765	87.1	3 (1P, 1F, 1A)
Dunedin	Dunedin City	28	12,078	12.0	5,560	9.4	5 (2P, 2F, 1H)
Oamaru	Waitaki	2	1,989	14.5	1,466	13.9	0
Queenstown	Queenstown-Lakes	2	1,546	6.2	1,027	8.2	0
Balclutha	Clutha District	2	1,105	25.4	1104	34.5	3 (1P, 1F, 1A)
Outram	Dunedin City	1	912	100.0	734	100.0	1 (1F)
Milton	Clutha District	1	839	39.6	827	41.1	2 (1F, 1A)
Luggate	Queenstown-Lakes	1	461	73.5	365	76.2	1 (1F)
Glenorchy	Queenstown-Lakes	1	351	96.6	467	86.8	0
Waihola	Clutha District	1	324	63.1	346	65.0	0

Table E9: Flood hazard exposure **for rural areas** outside of urban areas – rural settlements by **district** ordered by population count.

Location	District	Communities with high or very high exposure	Population (count)	Population (% of location)	Buildings (count)	Buildings (% of location)	Critical Community Facilities (CCF)
Rural	Dunedin City	23	2071	29.8	4129	32.7	0
Rural	Clutha District	24	1150	16.4	2176	15.9	0
Rural	Central Otago	25	1081	14.4	2734	14.1	1
Rural	Waitaki	12	712	12.6	1379	11.8	0
Rural	Queenstown-Lakes	11	383	9.9	1025	14.0	0
Otago rural	**Total**	**95**	**5398**	**17.4**	**11443**	**17.7**	**1**

6.0 Limitations overview

6.1 Population datasets

Transient population counts (e.g. tourists, short term visitors) are not included in the analysis. This is because 1) appropriate statistics on transient population counts are not available at the community unit scale, and 2) the transient population fluctuates over comparatively shorter time frames (days-weeks) to that of the usual resident population (months-years), rendering it inappropriate for the temporal scale of the analysis (in alignment with official census counts, approx. 4-yearly).

6.2 NZ Building Inventory

The NZ Building Inventory dataset reflects building outlines and property information as of June 2024, hence changes after this date are not reflected in the dataset used for the analysis. This is not expected to cause any significant changes to the analysis findings however (i.e., rate of new building construction over this time is not considered to be significant compared to rest of the dataset). The source dataset is updated in line with aerial and satellite imagery availability (every few years) and can be used to re-run the analysis where updates are available.

As touched upon in Scheele et al (2023), significant gaps exist in building attribute information for rural areas in the dataset, including the building use category classification. This holds true for rural areas of Otago where many buildings do not have a use category assigned. Upon examination of the dataset using aerial and satellite imagery, open street map, google street view (where available) and available property datasets (e.g. LINZ parcels, ORC property information, Otago district rates information etc.), an approach is developed to distinguish farm/rural dwellings from general farm type buildings in the dataset (section 4.2.4) for buildings without an assigned use category. This approach develops criteria interpreted to be specific to dwellings (e.g. roof characteristics, building footprint size, evidence for family residence etc.) to improve building classification and support the UR population exposed calculation (section 4.2.4). Further work is suggested to calibrate this approach in more detail to confirm building use categorisation (e.g. site visits where street view is not available).

In the current analysis, only a very small number of buildings (<100) have been classified using this approach, hence it is unlikely to have any major impact on the UR population exposed results for rural areas in the region. Nonetheless further work is recommended to improve the classification of use category for buildings in rural areas of the NZ Building Inventory dataset and hence improve the identification and classification of dwellings for future iterations of the exposure analysis.

6.3 Proposed ORPS exposure table and elements at risk

Elements at risk used in the analysis

Lifelines infrastructure and the social/cultural buildings elements are not considered in this phase of the analysis. Please see section 2.1 for a description on the rationale for this.

6.4 Natural hazards dataset mapping

Accuracy of mapped extents

This analysis maps the location of buildings within the mapped extents of natural hazards. The features mapped for some of the datasets (e.g. landslides, alluvial fans, Tsunami etc.) have a boundary extent accuracy of +/- 100 m, hence more or less buildings may be counted when determining those affected by the occurrence of the natural hazard.

Mapped natural hazard extent and elements exposed

The mapped natural hazard areas used in this analysis represent the full known extent of natural hazard occurrence based on current knowledge. i.e. a worst-case scenario based on current knowledge (past events, modelling etc).

In this case, all elements at risk located within the mapped extents are counted as exposed. This assumption is on the conservative side but is considered appropriate given the limitations of the source datasets and scale of the analysis (community to district-regional). In practice however, potentially less elements maybe counted as exposed in smaller magnitude events where less ground area is affected and hence the mapped extent is smaller.

Landslide mapping

Mapping of the lower boundaries of landslides may not cover the full extent of runout, particularly in areas outside the Dunedin coastal area. The Dunedin coastal area has been mapped more recently (Barrell et al, 2017) using more up to date technology (e.g. lidar) and thus boundaries are expected to be more accurate for these features, including interpreted runout zones, than for the comparatively older information mapped elsewhere in the region.

6.5 Overall exposure analysis

UR population exposed estimate

The use categories used to define dwellings in the analysis are argued to best reflect place of residence of the usual resident population in Otago. Despite this, some other use categories may include dwellings e.g. buildings classified as appurtenant, mixed residential/non-residential, farm in rural areas etc. This may in turn result in an undercount of the UR population exposed as the average UR population per dwelling statistic is used in the calculation of UR population exposed where a dwelling intersects a mapped hazard extent. In urban areas, this is not expected to be significant as the classification of building type is relatively comprehensive. In rural areas, the classification of use category is less well defined as described in Scheele et al (2023). Future iterations of the NZ Building Inventory could make use of image classification techniques based on spectral and optical characteristics of building features (as per Table 5) to improve the classification of buildings in these areas, and hence improve the overall estimate of UR population exposed.

In order to calculate an estimate for UR population residing in rest homes, the total bed count for each facility is multiplied by the average occupancy statistic (87%) for rest homes in Otago (see section 4.2.4). This is an average metric of resident occupancy for all rest home facilities across the region. In practice, occupancy may vary between facilities. Despite this, the average occupancy statistic is considered scale appropriate for the analysis (community and district level), enabling a good estimate on UR population residing in rest homes across the region.

Mapped vs unmapped areas

The exposure analysis has only been carried out for areas where mapped natural hazard information is available. This means that some areas where a natural hazard is a known significant threat, but where mapping is not yet available, will not be included in the results. South Dunedin is a primary example of this where large areas are subject to pluvial flood hazard, as demonstrated in recent events (e.g. June 2015, October 2024), but where adequate mapping for this type of hazard has not yet been carried out.

For further details on the limitations of the source datasets used in the analysis and the Otago Natural Hazards Risk Assessment in general, please refer to the exposure technical analysis report (van Woerden and Welsh, 2025).

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