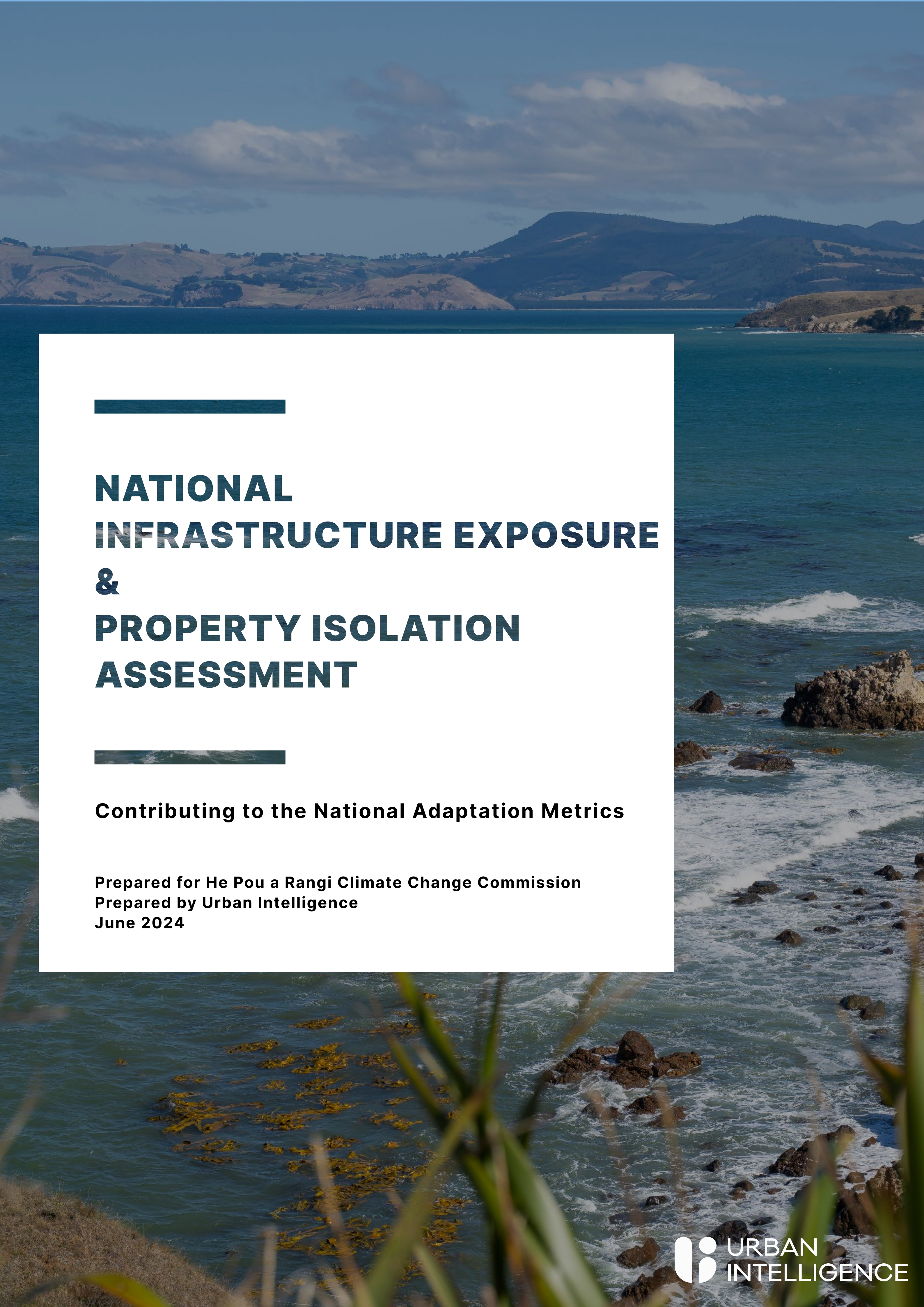

NATIONAL INFRASTRUCTURE EXPOSURE & PROPERTY ISOLATION ASSESSMENT

Contributing to the National Adaptation Metrics

Prepared for He Pou a Rangi Climate Change Commission
Prepared by Urban Intelligence
June 2024

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National Infrastructure Exposure & Property Isolation Assessment

Prepared by: Urban Intelligence Ltd.

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Version 1.0	Complete report	30 June, 2024
Version 1.1	Minor figure corrections	July 11, 2024
Version 1.2	Correcting isolation results	July 17, 2024

Contents

Executive Summary

As has been highlighted again following recent events, Aotearoa New Zealand is at risk from extreme weather. Changing environmental conditions, such as sea level rise from vertical land movement and climate change, will exacerbate this risk to critical infrastructure and residents. Understanding the risk, where it is, and the timeframes by which it is changing, provides the evidence for New Zealand to ensure our infrastructure, communities, and economy are resilient.

To this end, this report assesses the exposure and isolation risk faced by critical infrastructure, communities, properties, and marae in New Zealand due to coastal flooding and landslides. The analysis provides a snapshot of current risks and projects how they may evolve with sea level rise. The assets considered include roads, property, hospitals, schools, fire stations, airports, and electricity transmission structures.

This assessment is based on two key metrics:

1. **Exposure:** This metric quantifies the extent of buildings and infrastructure located in areas prone to coastal flooding or landslides.
2. **Isolation:** This metric identifies properties and communities that may become cut off from essential services such as hospitals, schools, and emergency services due to impacts on the transport network, even before direct inundation occurs.

The analysis focuses on two primary hazards: coastal flooding and landslides. Coastal flooding is assessed using a 1% Annual Exceedance Probability (AEP) event under various sea-level rise (SLR) scenarios. A 1% AEP event, often referred to as a '100-year flood', has a 1% chance of occurring or being exceeded in any given year. It is important to note that this doesn't mean such an event only occurs once every 100 years; in fact, there's a 26% chance of experiencing at least one such event in a 30-year period. Landslide risk is based on current landslide-prone areas, as identified in national datasets. While climate change is expected to exacerbate landslide frequency and intensity due to changes in rainfall patterns, the analysis uses current landslide risk zones as modelling of considering future changes is unavailable.

Short-term Risks

Within the next few decades, with just 20cm of sea-level rise, significant infrastructure is at risk. Fourteen airports (15% of total), over 1,300 bridges (8%), and 2,000 km of roads (1.4% of national network) are exposed to coastal flooding. Additionally, 60 km of rail, 106 schools, 15 fire stations, and 6 hospitals face exposure risks.

Approximately 37,200 properties, affecting over 69,000 residents, are at risk of direct exposure to coastal flooding. However, when considering isolation risk, this number increases to about 80,000 properties, affecting over 140,000 residents. Marae face similar risks, with 116 (11% of total) at risk of isolation from coastal flooding, while only 14 (~1%) are directly exposed.

Landslides pose a separate threat, with approximately 1,200 km of roads, 130 bridges, and 513 transmission structures exposed.

Most Affected Areas

The risks are not evenly distributed across the country. For coastal flooding with a 1% annual chance of occurrence and 20cm of sea-level rise:

- Napier has 26% (5,940) of its properties and 33% (9) of its schools exposed.
- Hauraki has 24% (235 km) of its roads and 30% (7) of its schools exposed.
- Christchurch has the highest number of exposed properties (6,040, 4% of total) and schools (11, 8% of total).
- Thames-Coromandel has 50% (2 out of 4) of its airports exposed.

In terms of population isolation, to the same coastal flooding event with 20cm SLR:

- Thames-Coromandel has 35% (10,500) of its residents at risk.
- Buller has 29% (2,800) of its residents at risk.
- Kaipara has 26% (5,900) of its residents at risk.
- Hauraki has 25% (5,000) of its residents at risk.
- Napier has 25% (16,000) of its residents at risk.

For landslides, the exposure risks are particularly high in:

- Porirua, with 33% (1 out of 3) of its fire stations exposed.
- Wellington, with 6% (24 out of 401) of its transmission structures exposed.
- Waimakariri, with 29% (8 km) of its rail network exposed.
- Kaipara, with 33% (2 out of 6) of its fire stations exposed.
- Hauraki, with 33% (2 out of 6) of its fire stations exposed.

When considering isolation risk due to landslides:

- Wairoa has 17% (1,400) of its residents at risk of isolation.
- Thames-Coromandel has 12% (3,600) of its residents at risk of isolation.
- Waitomo has 11% (1,000) of its residents at risk of isolation.
- Ruapehu has 11% (1,300) of its residents at risk of isolation.

Long-term Projections

To estimate how the risk will change over time, the analysis uses the Intergovernmental Panel on Climate Change's climate scenarios and NZSeaRise's vertical land movement data. These climate scenarios, known as Shared Socioeconomic Pathways (SSPs), range from SSP1 (a scenario with lower rates of change that assumes strong mitigation efforts) to SSP5 (a scenario with higher rates of change).

Looking ahead to 2100, under the SSP1-2.6 scenario, the risks are projected to increase substantially. Road exposure to coastal flooding could reach 3,260 km (2.3% of the national network), while rail exposure could double to 120 km. The number of exposed schools could reach 166, with 35 fire stations and 8 hospitals also at risk. Property exposure nationwide could reach 61,700, with potentially 10,500 properties in Napier (about 45% of the city's total) exposed.

By 2150, the risk increases further. Under SSP1-2.6, exposure could reach 45% of properties in Napier, 30% in Buller, and 20% in Hauraki. Isolation risk could affect nearly 50% of properties in Napier, 40% in Thames-Coromandel, and 40% in Buller. Additionally, more than 350,000 residents nationwide could be at risk of isolation from hospitals due to coastal flooding.

These values represents a conservative (low) estimate of the risk as they are based on SSP1-2.6. Two recent surveys of international climate change experts found that more than 77% of respondents expect climate change to exceed 2.5^{o}C, aligning with the upper end estimates of SSP2-4.5, and around half expect more than 3^{o}C of warming, aligning with SSP3-7.0 and the low side of SSP5-8.5 [1, 2]. This means that the actual impacts could be significantly higher.

Demographic Considerations

The analysis reveals that certain socioeconomic groups face higher risks. Māori and European residents face the highest risk of isolation from both coastal flooding (at 20cm of SLR) and landslides compared to other ethnic groups. In terms of income, lower-income households (earning 0-40,000 NZD annually) have the highest percentage risk of isolation (>9%) from a 1% coastal flood event. People living in more deprived areas (NZDep 7-10) also typically face higher risks of isolation from coastal flooding.

Implications

This analysis finds that significant infrastructure and property are already at risk from coastal flooding and landslides, with these risks projected to increase over time due to sea-level rise. The disproportionate impact on certain regions and demographic groups highlights the need for urgent and targeted attention.

This report provides a foundation for understanding these risks, emphasising the importance of ongoing monitoring and assessment. As climate conditions, demographics, infrastructure, and land use continue to change, regular updates to these assessments will be crucial for maintaining an accurate understanding of the evolving risk landscape in New Zealand.

1 Introduction

Changing natural hazards due to climate change pose significant risks to communities, infrastructure, and the environment. Understanding and quantifying these risks is critical for informing and evaluating adaptation plans. This report introduces and evaluates two national risk metrics for Aotearoa New Zealand that can aid in monitoring the country's adaptation to climate change and the potential future burden of these risks.

This report provides a snapshot of the current risk as it is currently understood. There are omissions (due to data availability at a national level) and limitations (that are continuously being addressed by ongoing research). Future assessments of these metrics will continue to improve our understanding of these risks and support how they are managed.

The first metric, **the extent of property and infrastructure in at-risk areas**, estimates the quantum of assets exposed to coastal flooding and landslides. When an asset is located within a hazard-prone area it is considered *exposed*. Exposed infrastructure is problematic due to the potential for damage, disruptions in service levels, and implications for insurance coverage. This potential for damage is called *vulnerability*. In detailed risk assessments, the combination of hazard, exposure, and vulnerability, and the associated uncertainty, is referred to as risk [3] (Figure 1). However, often, as in the case of this report, a risk assessment will consider exposure alone in order to identify areas that require further analysis or adaptation planning. If the asset is vulnerable to the severity of exposure, the resulting damage could lead to both direct and cascading consequences that impact communities, the natural environment, and the economy. The assets assessed for exposure in this report include roads, buildings, hospitals, schools, fire stations, marae, bridges, airports, electricity transmission structures, and rail.

The second metric, **property and marae isolation**, focuses on properties and marae that may become cut off from communities or lose access to critical services due to impacts on the transport network, even before direct inundation occurs. In some areas, isolation may arise significantly earlier than inundation, as transport routes may be more exposed and vulnerable than the properties themselves. This metric highlights the importance of considering connectivity and other indirect impacts as part of adaptation planning.

As the first of their kind for Aotearoa New Zealand, these metrics provide an initial baseline to support monitoring and evaluation of adaptation planning and action over time. While detailed and spatially explicit risk information is required at the local and regional government level to enable effective adaptation planning, these national metrics offer a high-level perspective on the potential risks and burdens posed by climate change-induced natural hazards.

Climate change is expected to exacerbate natural hazards, such as coastal flooding and landslides, due to factors like sea-level rise and changes in rainfall patterns [4]. Ideally, risk assessments should consider a range of hazards across climate projections, but for now, monitoring these two hazards represents an important step in developing our understanding of how risk is changing over time. Landslides and coastal flooding were selected due to the availability of nation-wide datasets and their significance for New Zealand, given the country's extensive coastline and mountainous terrain. As risk information becomes available around the country, this may be able to be aggregated to provide a more complete national picture.

By understanding and monitoring these national risk metrics (infrastructure exposure and property isolation), decision-makers can gain critical foundational information about the changing nature of risks posed by climate change-induced natural hazards. These metrics provide valuable insights into the potential impacts on infrastructure, property, and connectivity, which have significant implications for the resilience and well-being of communities across Aotearoa New Zealand. Tracking these metrics over time will help to understand how risk is evolving and where additional research, policy development,

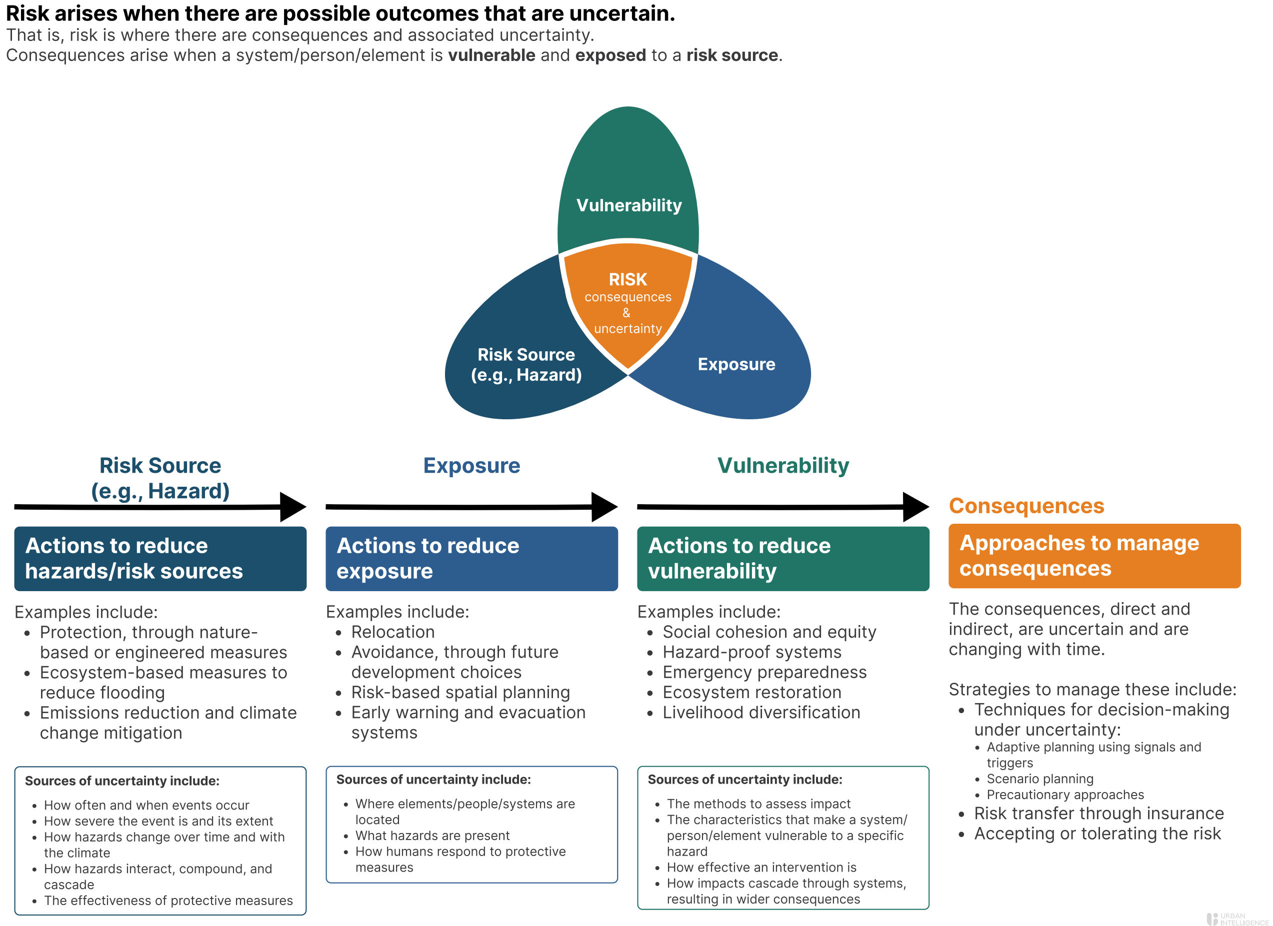

Figure 1: Risk is the consequences and associated uncertainty. This exists if something of value (like a community, asset, or ecosystem) is exposed and vulnerability to a risk source (e.g., a hazard).

and support may be needed to bolster adaptation efforts. While these two metrics alone do not provide a comprehensive basis for specific policy recommendations, they represent an important step in developing a more complete understanding of the risks associated with climate change and informing the development of strategies to mitigate potential impacts.

1.1 Exposure: Extent of Property and Infrastructure in At-Risk Areas

The first of the two national risk metrics examined in this report is the extent of property and infrastructure exposed to coastal flooding and landslides. This metric provides a foundational understanding of the potential risks faced by critical infrastructure sectors and the communities that rely on them. By quantifying the exposure of these assets, decision-makers can better grasp the scale of the challenge and prioritise adaptation efforts accordingly.

Our communities rely on a range of infrastructure sectors to maintain connectivity, support well-being, and enable daily life. These sectors include buildings, transportation, healthcare, education, emergency services, cultural facilities, energy distribution, waste management, and telecommunications. Each of these sectors plays a vital role in providing essential services, housing and venues for employment etc., facilitating the movement of people and goods, ensuring public safety, and supporting the social and economic well-being of communities. Given the importance of these infrastructure sectors, understanding their exposure to natural hazards and how this exposure may change and exacerbate over time due to climate change is necessary for assessing potential risks and impacts on the communities that depend on them.

Exposure to hazards is an indication that an asset may be disrupted. That is, there is the potential for damage, which can lead to disruptions or reductions in the level of service. For example, major impacts may arise due to forced displacement of communities or severe economic and wellbeing disruption caused by infrastructure disruptions [5]. Another critical concern is the high likelihood of insurance withdrawal for properties and infrastructure. Recent research by Storey et al. (2024) [6] found that 99% of properties currently within 1% AEP coastal inundation zones in four Aotearoa New Zealand cities can expect at least partial insurance retreat within a decade, with less than 10 cm of sea-level rise. Their study predicts that full insurance retreat is likely within 20-25 years, depending on the property's elevation, distance from the coast, and the tidal range in each location. While this research focuses on properties, the added scrutiny and potential for insurance retreat extends to other infrastructure assets as well. As the risks associated with natural hazards increase due to climate change, insurers may reassess the insurability of exposed infrastructure, potentially leading to higher premiums or withdrawal of coverage. This could leave a significant portion of critical infrastructure assets and homes without financial protection, placing a burden on asset owners and communities to manage the costs of potential damages and disruptions.

If the exposure is severe enough and the infrastructure is vulnerable, the resulting damage could lead to cascading consequences. These consequences will vary based on each infrastructure sector, with a range of implications for communities, the natural environment, and the economy. For instance, damage to waste management facilities, such as landfills, presents significant risks to the natural environment due to potential contamination. Similarly, disruptions to transportation networks can hinder the movement of people and goods, impacting supply chains and emergency response efforts [7, 8]. Damage to electricity distribution infrastructure can cause widespread outages that can result in failure of other infrastructure such as water supply and wastewater [9]. Damage to healthcare and education facilities can compromise the delivery of essential services, while impacts on cultural facilities may lead to the loss of important community hubs and cultural heritage. These impacts can have significant flow-on effects to communities and socio-economic well-being and resilience [10]. These examples illustrate the far-reaching and interconnected nature of cascading consequences, highlighting the need for a holistic approach to understanding and mitigating the risks posed by natural hazards. By recognising the potential for impacts to propagate across infrastructure sectors and into communities, decision-makers can develop more effective adaptation strategies that account for the complex interdependencies within and among critical systems. Failure to do so may lead to underestimating the true scale of the challenges posed by climate change and missed opportunities to build resilience in the face of growing risks.

In this analysis, we estimate the quantum of properties and infrastructure exposed to coastal flooding and landslides. Exposure is defined as an asset being located within a hazard-prone area. In this report, the following assets and infrastructure types are considered:

- Roads
- Buildings (reported per property)
- Hospitals
- Primary schools
- Fire stations
- Marae
- Bridges
- Airports
- Electricity transmission structures
- Rail.

Detailed descriptions of each dataset can be found in Table 1. Note that individual buildings are *assessed, but are reported at the property level. These buildings and property include all use types (not limited to residential).*

The set of infrastructure included in this analysis was chosen due to their critical importance for connectivity, well-being, and functioning of communities across Aotearoa. These assets play important roles in transportation, healthcare, education, emergency services, and energy distribution. Disruptions to these assets can have far-reaching consequences for the communities that rely on them.

This list does however, omit several other critical infrastructure types, such as water supply, wastewater, waste management, and telecommunications infrastructure. These assets are important for their roles in maintaining public health, enabling communication, and supporting daily functioning of communities. Their omission from this analysis is due to the limited availability of comprehensive, nationwide datasets. Much of this data is held by local entities (councils and asset owners) around the country. As this data is compiled into nationally consistent datasets or local spatial risk assessments are conducted in a manner that they can be aggregated up, future iterations of this metric can incorporate a broader range of critical infrastructure. Despite these omissions, the infrastructure types included in this analysis represent a significant portion of the built environment and provide valuable insights into the potential risks and impacts associated with these natural hazards.

Although this study focuses on landslides and 1% AEP coastal flooding, evidence suggests that impacts will occur that are not just linked to extreme events, but to the related, gradual changes. For instance, studies indicate that coastal flooding, and the groundwater rise associated with sea-level change, is linked to obstruction of drainage systems, which increases the risk from other sources of flooding [11, 12, 13]. Furthermore, road pavements deteriorate significantly faster when flooded or when groundwater moves into the underlying layers of the pavement [14, 15, 16].

These burdens on infrastructure are associated with sea-level change and tidal flooding. Such burdens will also lead to impacts on the communities relying on the infrastructure. To better capture this burden, it is important to consider an additional metric that begins to encapsulate how communities interact-with and rely-upon infrastructure. In this report, we use isolation as that measure.

1.2 Isolation: Properties and Communities Cut-Off From Key Amenities

Isolation occurs when properties are cut off from communities and critical services due to impacts on the transport network. In some areas, isolation may occur decades earlier than direct exposure because transport routes are often more exposed and vulnerable than the properties themselves [8]. Using isolation as a complementary metric to exposure provides insights into the number of people dependent on specific road segments and highlights where alternative transport modes or approaches to receive or access services need to be considered.

The risk of isolation is particularly salient for several reasons:

1. Loss of Access to Essential Services: Isolation signals a loss of access to and from essential services like supermarkets, workplaces, education facilities, emergency services, and cultural sites of significance (such as marae). This loss of access can have profound impacts on community well-being and resilience.
2. Disruption to Critical Infrastructure: Isolation often indicates potential disruption to horizontal infrastructure that is frequently co-located with roadways. When a property loses road access, other essential services like electricity, water, and internet may also be affected, compounding the challenges faced by isolated communities.
3. Impacts on Community Functioning: Access to essential services, such as education, healthcare,

and emergency response, is critical for the day-to-day functioning and well-being of communities. Disruptions to these services, whether due to direct impacts on the facilities themselves or the transportation networks connecting them, can have far-reaching consequences for public health, safety, and social equity.

4. Exacerbation of Inequities: The National Climate Change Risk Assessment (NCCRA) identified the risk of exacerbating existing inequities and creating new ones due to the differential distribution of climate change impacts as extreme and urgent (H2) [4]. This risk is closely linked to people's ability to access resources, participate in daily life, and respond to challenges. Isolation can amplify these inequities.

5. Strain on Emergency Management: The NCCRA also highlighted the risk to the emergency management system's ability to respond to an increasing frequency and scale of compounding and cascading climate change impacts (G6). As climate hazards intensify and become more frequent, the capacity of emergency services to meet growing demand may be compromised, especially if critical infrastructure is damaged or inaccessible.

6. Economic Resilience: Isolation, especially when recurring, can decrease the resilience of local economies through regular disruption of business activities, supply chains, and workforce mobility. This economic impact further underscores the importance of addressing isolation risk in adaptation planning.

The isolation metric represents an indirect risk, complementing direct exposure assessments. Other indirect impacts include loss of electricity or other utilities. These indirect effects can compound and be less intuitive and spatially variant than direct impacts, making them crucial to understand and manage. They may occur earlier than anticipated or affect areas previously thought to be unaffected.

From a policy perspective, understanding isolation risk allows for better consideration of if, where, and how to administer support in the face of sea level rise. This is especially important as impacts to property have a range of direct and indirect consequences, as described in the National Climate Change Risk Assessment. These impacts extend beyond the risk to the properties themselves, affecting social cohesion, exacerbating inequities, influencing physical and mental health, and causing economic disruptions arising from displacement and isolation. For example, central and local government adaptation planning face critical questions such as determining at what point a property is no longer habitable (i.e., when should support be provided?). The United Nations Universal Declaration of Human Rights, along with numerous other international conventions, identifies adequate housing as a human right, including access to necessary social services. However, these rights may be infringed as residents face temporary and ultimately permanent isolation due to rising sea levels and increasing frequency of extreme sea-level events, resulting in severe demands on residents' mental health and well-being.

While this report evaluates isolation risk primarily against landslides and coastal flooding (with a 1% annual exceedance probability) events, isolation can arise from other hazards as well. For example, tidal flooding linked to sea-level rise can lead to temporary isolation. Although such nuisance flooding may be short-lived, its regularity can have impacts on mental health, community well-being, and economic productivity as residents must continually plan their activities around these disruptions. As additional hazard data becomes available, including information on the frequency of events, an important step for local infrastructure providers will be to determine appropriate levels of service and tolerance to disruptions such as isolation.

The risk of isolation metric provides a spatially and temporally explicit indication of the localised burden from climate change impacts, complementing the more commonly used exposure metric. It highlights critical vulnerabilities in the transportation network and underscores the need for adaptation planning to consider burdens beyond just direct impacts.

Although this study primarily considers isolation due to disruption of road infrastructure, holistic adaptation planning should consider other modes of transportation, such as water-based options, to ensure community resilience. This metric thus serves as a valuable tool for identifying areas where such alternative strategies may be necessary to maintain critical connections and services in a changing climate.

2 Key Observations

2.1 Infrastructure Exposure

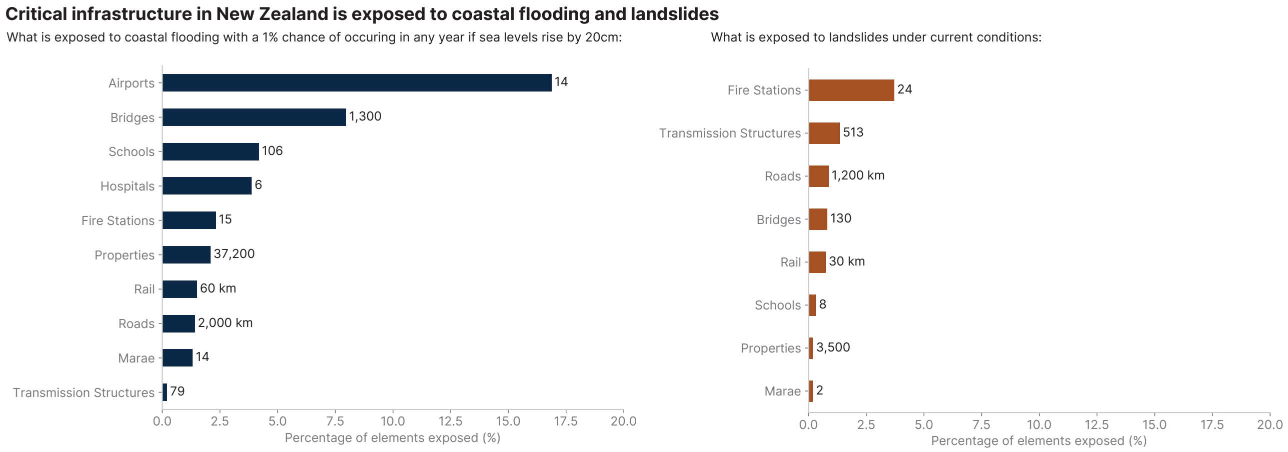

Figure 2: New Zealand's exposure statistics for coastal flooding and landslides, ranked by the percentage of the infrastructure type.

This section provides an overview of the key findings related to the exposure of critical infrastructure to coastal flooding and landslide hazards in New Zealand. Understanding the extent and spatial distribution of this exposure is a first step of identifying at-risk areas, prioritising adaptation efforts, and building resilience to climate change impacts for a range of infrastructure types, including roads, buildings, hospitals, schools, fire stations, marae, bridges, airports, electricity transmission structures, and rail. Coastal flooding exposure is assessed based on a 1% Annual Exceedance Probability (AEP) event under various relative sea levels (most figures in this report demonstrate a coastal flood under 20cm of relative sea-level rise). Landslide exposure is based on the current spatial distribution of landslide-prone areas, as climate change is expected to exacerbate the frequency and intensity of landslides due to changes in rainfall patterns.

The analysis reveals significant exposure of infrastructure and properties to coastal flooding and landslides across New Zealand (Figure 2). With just 20cm of sea level rise, expected within the next few decades [17], a substantial number of assets are at risk.

Short-term coastal flooding risk (20cm sea level rise):

- 14 airports (17% of total)
- Around 1,300 bridges (8% of total)
- 2,000 km of roads (1.4% of national network)
- 60 km of rail (1.5% of network)
- 106 schools (4.2%)
- 15 fire stations (2.3%)
- 6 hospitals (3.9%)
- 79 (0.2%) electricity transmission structures

- 37,200 (2%) properties (affecting over 69,000 residents, 1.5% of the population)
- 14 marae (1.3% of total)

Landslide exposure:

- 1,200 km of roads (0.9% of national network)
- 130 bridges (0.8% of total)
- 8 schools (0.3%)
- 24 fire stations (3.7%)
- 513 transmission structures (1.4% of total)
- 3,500 (0.2%) properties (affecting more than 5,500, 1% of, residents)
- 2 marae ($<$1% of total)

Airports are the most exposed type of infrastructure by percentage, with 14 airports in New Zealand exposed to flooding. Bridges rank second in exposure; more than 1,300 bridges are at risk of coastal flooding. The lack of data on water depth makes the high exposure of bridges expected and highlights the need for site-specific analysis in these areas.

The substantial number of schools, hospitals, and fire stations at risk to both hazards indicates risk-informed planning action is required as disruption to these critical facilities can have cascading impacts on public health, education, and emergency response capabilities, exacerbating the consequences of these hazards.

With increasing sea level rise, these impacts grow (Figure 3). With 40cm of sea level rise, the length of road nearly doubles. By 100cm of SLR, we expect nearly 200,000 people, 100,000 properties, and nearly 50 marae to be exposed to coastal flooding (Figures 7 and 11).

Future projections indicate a significant increase in exposure. By 2100, under the SSP1-2.6 scenario:

- Road exposure to coastal flooding could increase to 3,260 km (2.3% of the national network)
- Rail exposure could rise to 120 km (3.0% of the network)
- The number of exposed schools could reach 165 (6.5%)
- Exposed fire stations could increase to 30 (4.6%)
- Exposed hospitals could rise to 8 (5%)
- Property exposure could reach 60,000 nationwide (>3%)
- In Napier, property exposure could increase to 10,000 (nearly 45% of the city's properties)
- Christchurch could see 9,700 properties exposed (6.6% of the city's properties)

These projections are based on the SSP1-2.6 scenario, which assumes strong mitigation efforts and represents a lower-end estimate of potential climate change impacts. Recent surveys of international climate change experts suggest that actual warming might exceed these projections. More than 77% of surveyed experts expect global warming to exceed 2.5^{o}C, which aligns with the upper end estimates of SSP2-4.5, while approximately half anticipate more than 3^{o}C of warming, corresponding to scenarios

SSP3-7.0 and the lower range of SSP5-8.5 [1, 2]. Consequently, the actual impacts could potentially be more severe than those presented in this report under the SSP1-2.6 scenario.

The spatial distribution of infrastructure exposure varies considerably across New Zealand. For coastal flooding with 20cm sea level rise, districts such as Napier, Christchurch, and Hauraki have high infrastructure exposure. For example, Hauraki has 30% of schools and 24% of roads exposed, while Napier has 26% of schools and properties and 23% of roads exposed. In the case of landslides, Porirua, Kaipara, and Hauraki have over 33% of their fire stations in areas currently prone to landslides. Figures 4, 5 and 6 show which districts have the greatest percentage of their assets exposed.

The amount/number of critical infrastructure exposed to coastal flooding will increase as sea levels rise

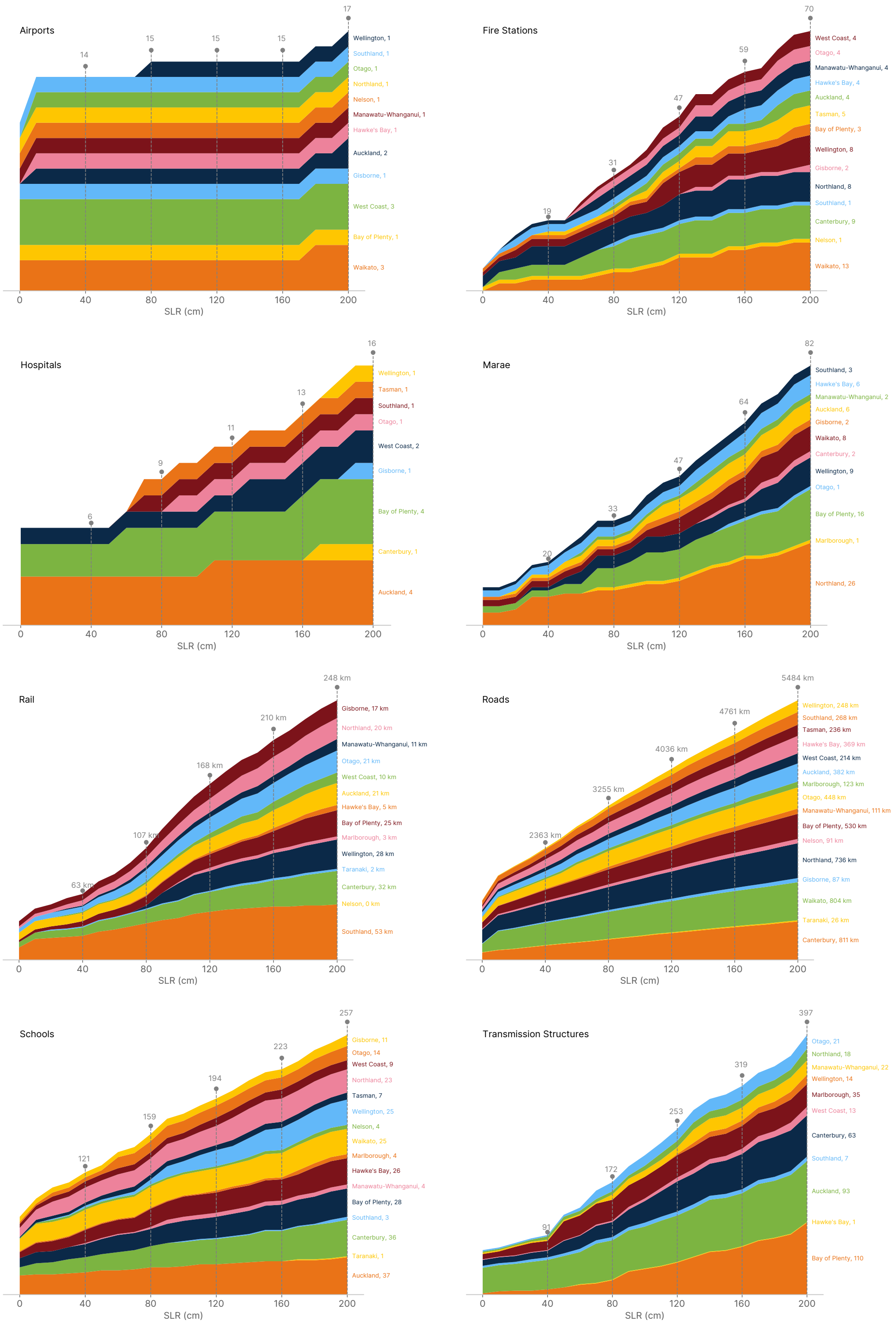

Figure 3: These figures show Aotearoa's infrastructure exposure to increments of sea-level rise, split by region.

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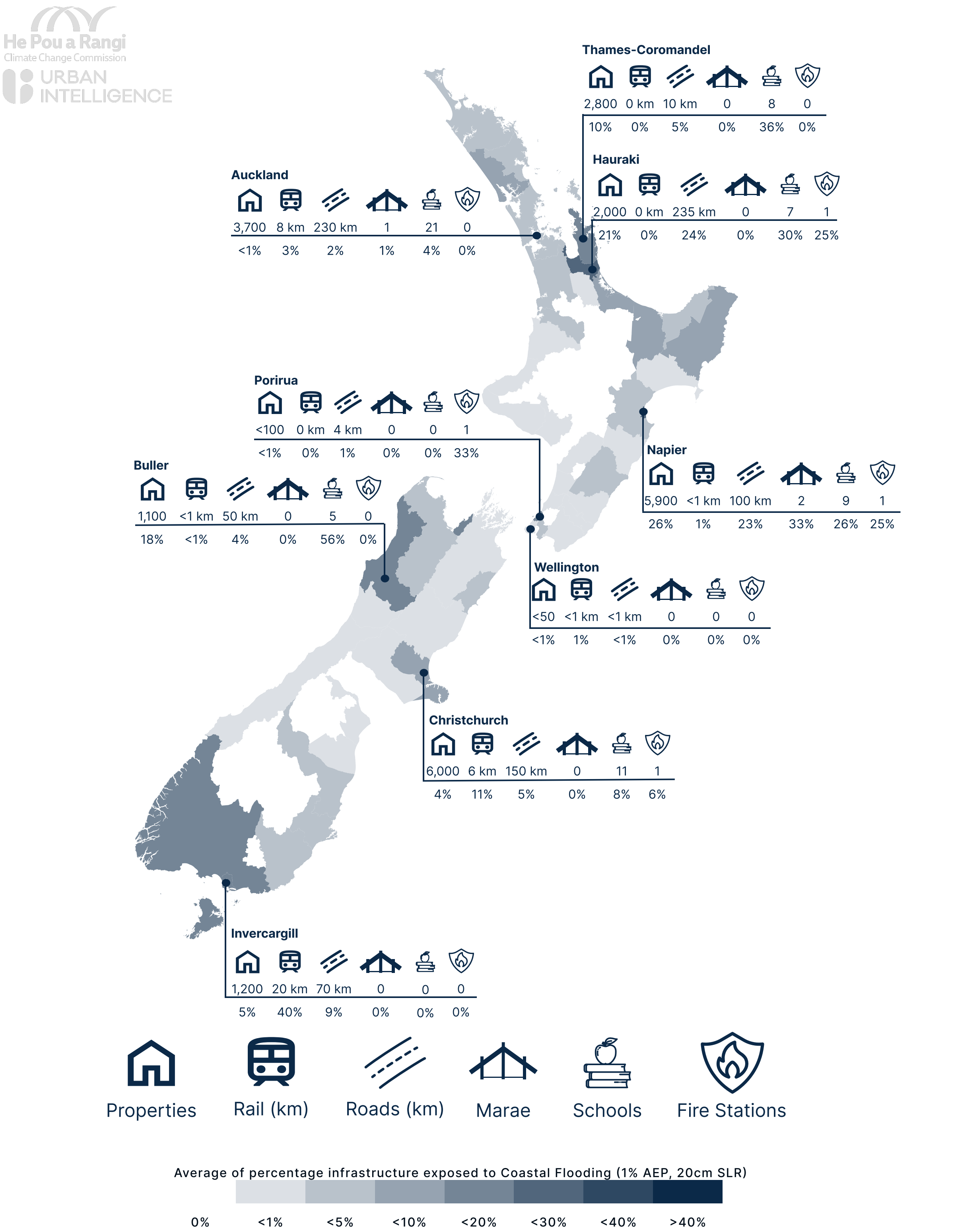


Figure 4: This map of districts is shaded according to the average percentage of infrastructure exposed to a 1% AEP coastal flooding event with 20cm of relative sea level rise. We provide details of the six districts with the highest percentage exposure, along with Auckland, Christchurch, and Wellington, are shown.

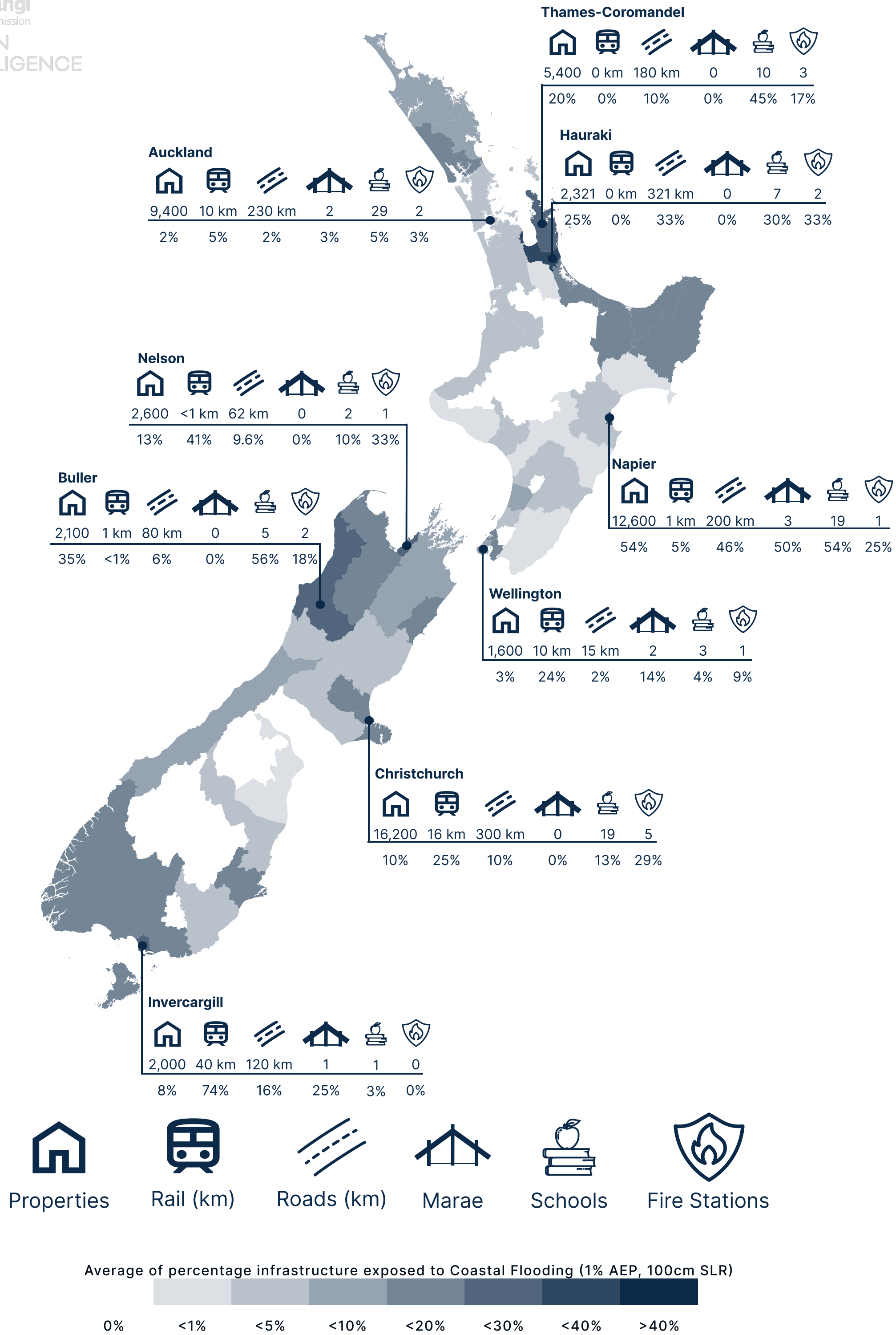


Figure 5: This map of districts is shaded according to the average percentage of infrastructure exposed to a 1% AEP coastal flooding event with 1m of relative sea level rise. The six districts with the highest percentage exposure, along with Auckland, Christchurch, and Wellington, are shown.

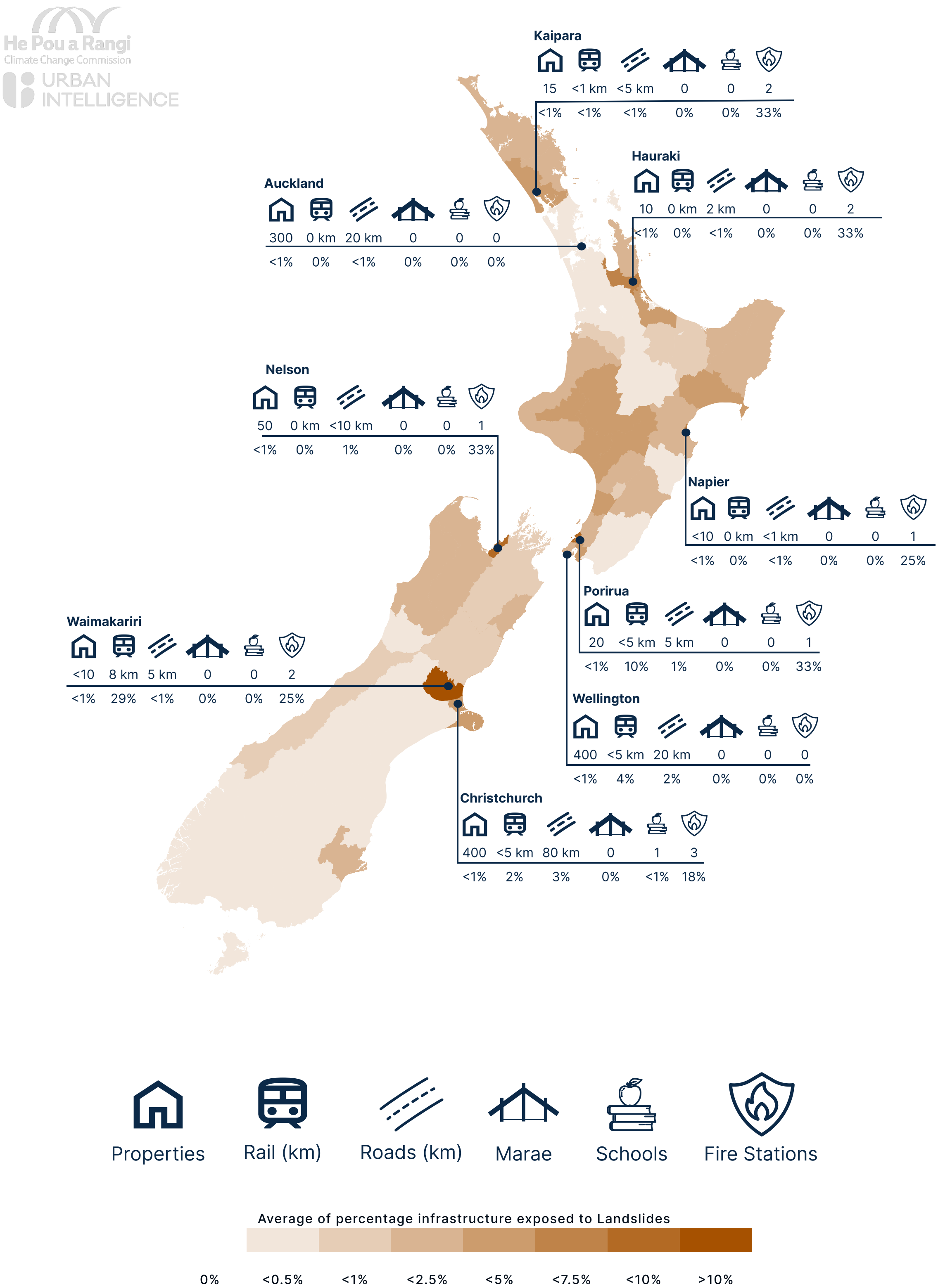


Figure 6: This map of districts is shaded according to the average percentage of infrastructure located in areas that are exposed to landslides. The six districts with the highest percentage exposure, along with Auckland, Christchurch, and Wellington, are shown.

2.2 Property and Marae Isolation

Isolation risk emerges as a concern, affecting a larger number of properties and marae compared to direct exposure. Isolation occurs when properties are cut off from communities and critical services due to impacts on the transport network. With 20cm of sea level rise, expected within the next few decades (Figure 7)

- Approximately 80,000 properties (affecting over 140,000 residents) are at risk of isolation from coastal flooding, compared to 37,200 properties at risk of direct exposure.
- 116 marae (11% of total) are at risk of isolation from coastal flooding, while only 14 marae (~1%) are directly exposed.

In some areas, isolation will occur earlier than direct exposure because transport routes may be more exposed than the properties themselves. Figures 8, 9, and 10 show the districts with the highest percentage of population at risk of isolation due to coastal flooding and landslides, respectively. For coastal flooding, Napier, Hauraki, Kaipara, Thames-Coromandel, and Buller have over 25% of their population at risk of isolation with 20cm of sea-level rise. In Christchurch, more than 20,000 residents are at risk from isolation. For landslides, Wairoa, Waitomo, Ruapehu, Rangitikei, and Thames-Coromandel have over 10% of their population at risk of isolation.

By demographic, Māori and Europeans face similar percentage risk of isolation from both hazards at around 4% (29,300 Māori and 112,600 European) live in areas at risk of isolation. Lower-income households (earning 0-40,000 NZD annually) show the highest percentage risk of isolation (>4%) and more deprived areas (NZDep 7-10) generally face higher risks of isolation from coastal flooding.

By 2100, under the SSP1-2.6 scenario, the following number of people, property, and marae could be at risk of isolation from coastal flooding (Figure 24):

- More than 200,000 people.
- Approximately 100,000 properties.
- Approximately 150 marae.

Isolation has the potential to be an additional burden to New Zealanders beyond the direct exposure to hazards

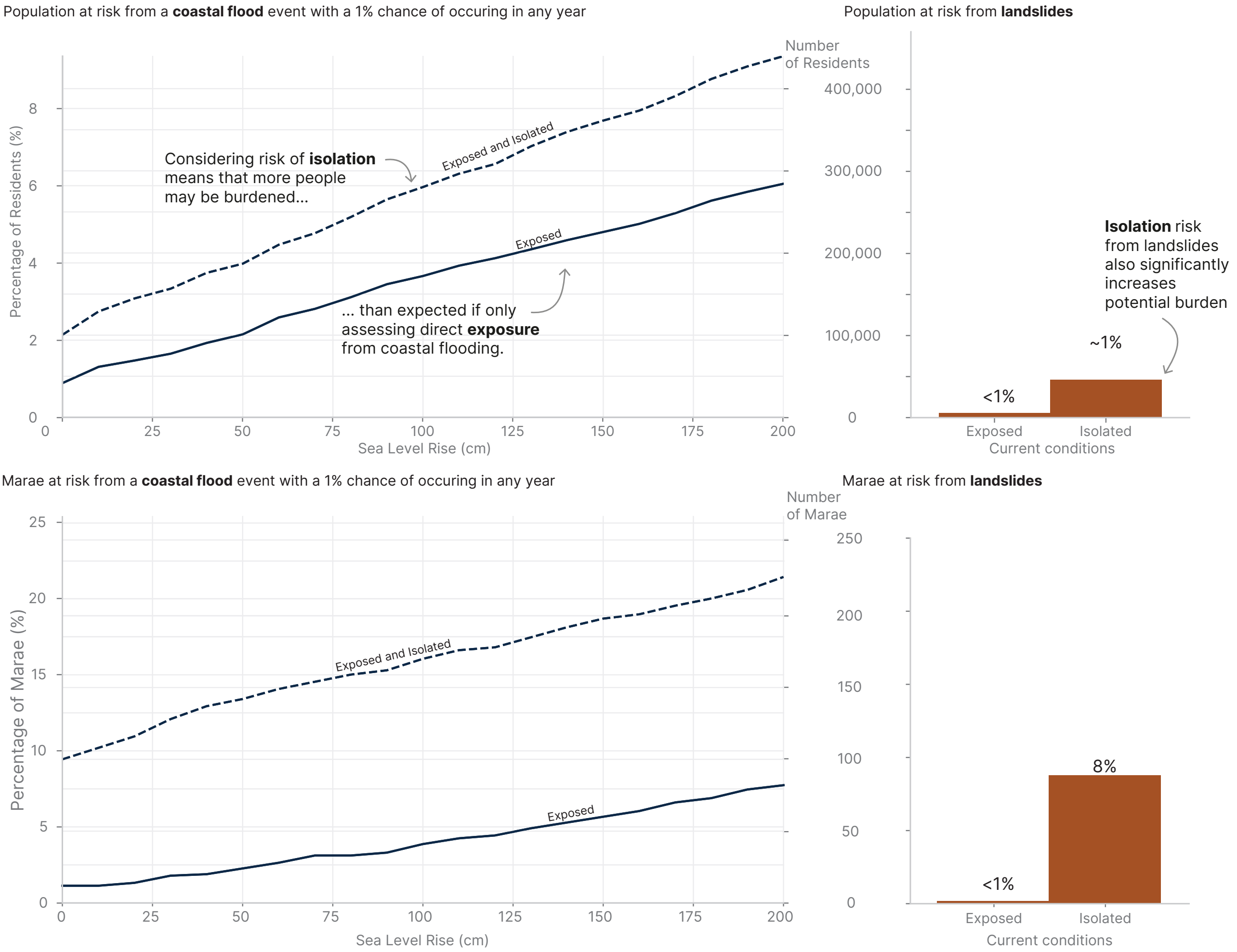


Figure 7: The risk of isolation and exposure from coastal flooding and landslides to marae and people.

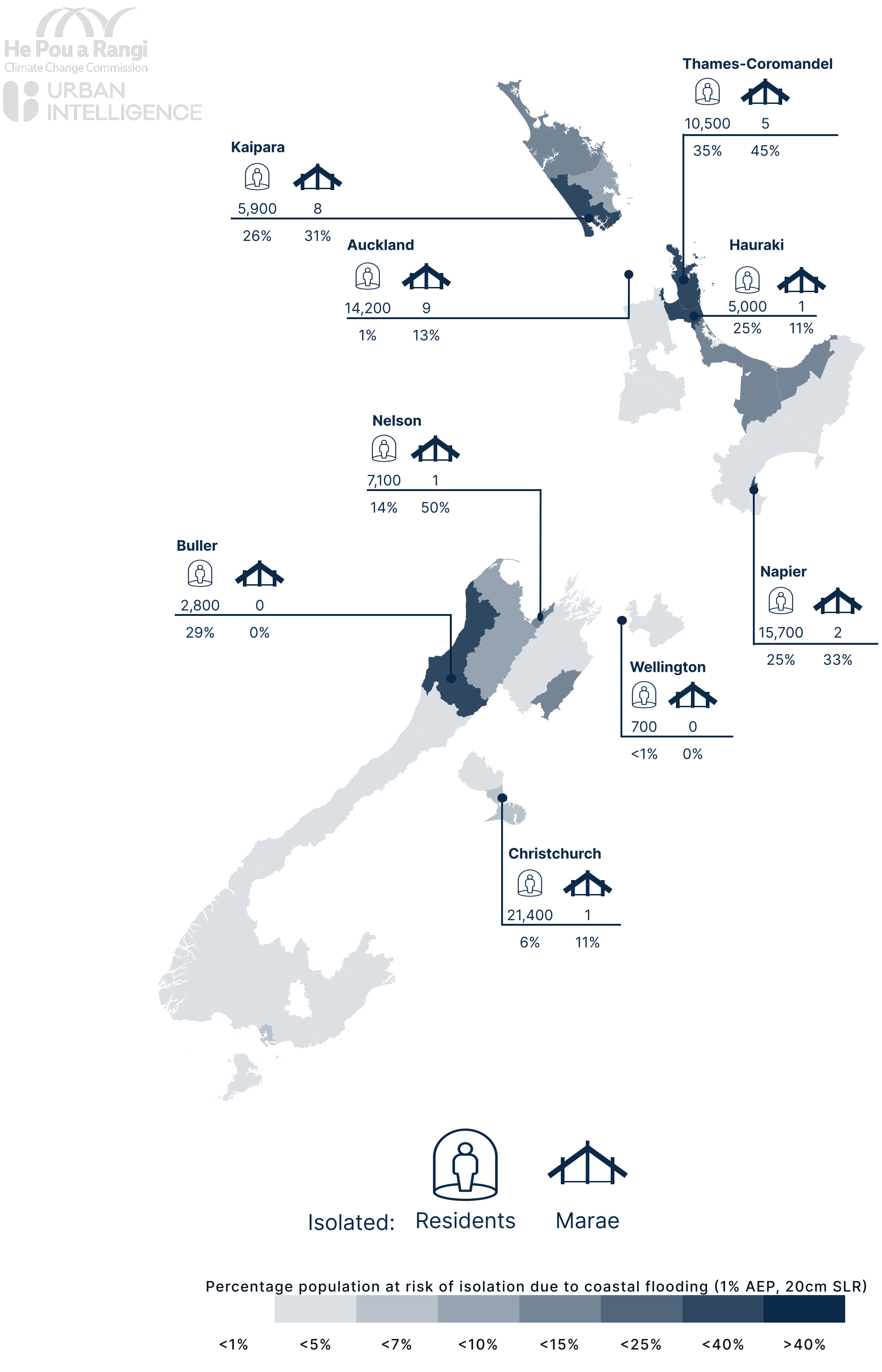


Figure 8: This map shows Aotearoa's districts, shaded by the percentage of their isolated population located in areas that, with 20cm of relative sea-level rise, would have more than 1% probability of coastal flooding (the 1% AEP zone). The six districts with the highest percentage isolation, along with Auckland, Christchurch, and Wellington, are shown.

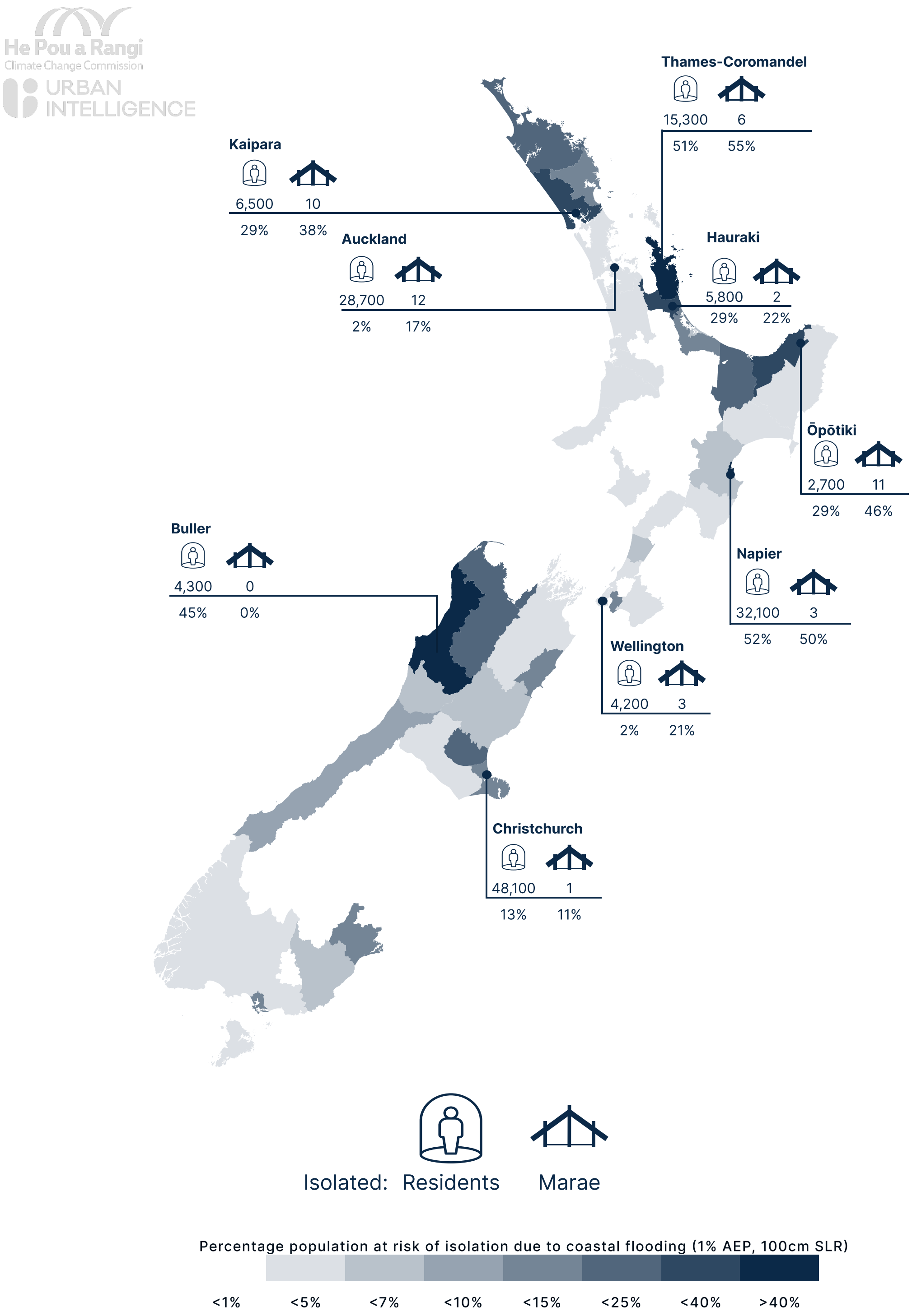


Figure 9: This map shows Aotearoa's districts, shaded by the percentage of their isolated population located in areas that, with 1m of relative sea-level rise, would have more than 1% probability of coastal flooding (the 1% AEP zone). The six districts with the highest percentage isolation, along with Auckland, Christchurch, and Wellington, are shown.

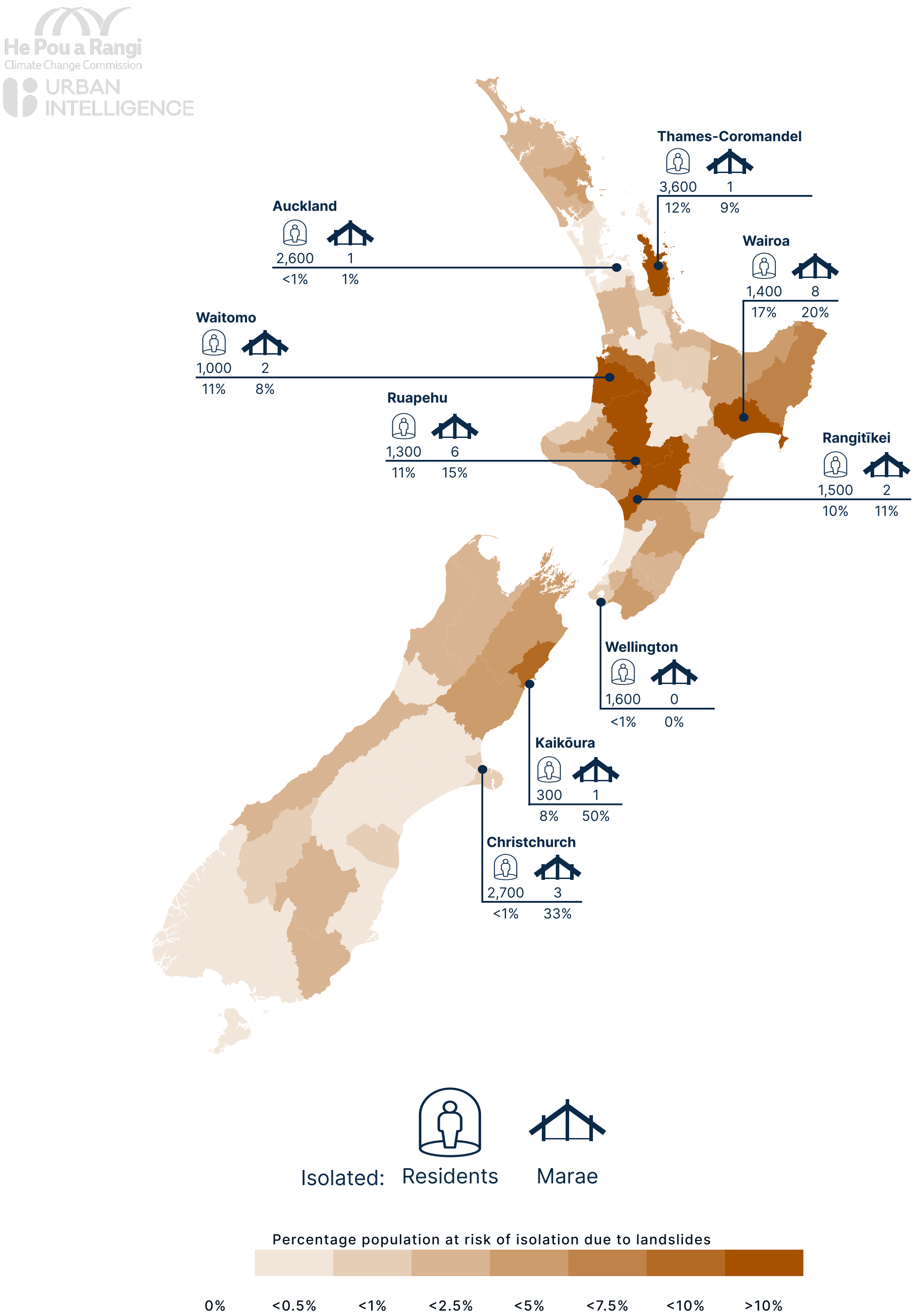


Figure 10: This map shows Aotearoa's districts, shaded by the percentage of their population located in areas that are isolated from landslides. The six districts with the highest percentage isolation, along with Auckland, Christchurch, and Wellington, are shown.

3 Results: Property and Infrastructure

3.1 Property

Understanding the risk to property supports developing effective adaptation policies. Two key dimensions of this risk are exposure and isolation.

Exposure refers to property located in hazard-prone areas, where homes, workplaces, and other facilities are threatened with damage and may present a risk to life. Isolation risk occurs when properties may be cut off from critical services (such as education, healthcare, and food) or lose infrastructure services (like electricity and potable water) due to the co-location of these services with transport corridors.

These risks are particularly relevant in New Zealand due to concentrated coastal development and mountainous terrain susceptible to coastal inundation and landslides, respectively. Rising sea levels will exacerbate the exposure and isolation risk of buildings to coastal flooding. For example, in 2015, 800 homes were flooded in South Dunedin from a high tide coinciding with extreme rainfall. This gave rise to over $28million in insurance claims [18].

Figure 11 illustrates the isolation and exposure risks for coastal flooding (with changing sea level) and landslides. Key findings include:

- Coastal flooding (1% AEP, 20cm sea level rise):
  - Approximately 37,200 properties (affecting over 69,000 residents) are at risk of exposure.
  - When considering isolation risk, this increases to about 80,000 properties (affecting over 140,000 residents).
  - 4% of properties nationwide are at risk of isolation.
- Landslides:
  - Approximately 3,500 properties (affecting 5,000-6,000 residents) are at risk of exposure.
  - When considering isolation risk, this increases to about 26,000 properties (affecting around 45,000 residents).
  - ~1% of properties nationwide are at risk of isolation.

With 20cm of sea level rise the highest number of exposed properties are in Christchurch (6,040, 4%), Napier (5,940, 26%), Auckland (3,740, ~1%), Thames-Coromandel (2,780, 10%), and Tauranga (2,070, 4%). By percentage, Napier, Hauraki (1,990, 21%), Buller (1,080, 18%), Kaipara (1,480, 11%), Whakatane (1,650, 11%), and Thames-Coromandel are the highest, all with more than 10% of their properties exposed.

When considering isolation risk from the same coastal flooding event, Christchurch (11,000, 7%), Auckland (6,000, 1%), and Thames-Coromandel (8,200, 31%) have the highest number of affected properties. By percentage, Thames-Coromandel, Buller (1,800, 30%), and Kaipara (3,500, 27%) are the most affected. Figure 12a and Figure 12c show these results, ranked by the percentage of the number of properties within the district. The relative exposure of properties within a district is important to understand as this percentage may have severe implications for the ratings base of these districts the future.

For landslides, while direct exposure is generally lower, isolation risk remains significant. Thames-Coromandel, Whangarei, and Christchurch face the highest risks by number, while Wairoa, Waitomo, and Thames-Coromandel face the highest risks by percentage (Figures 12b and 12d).

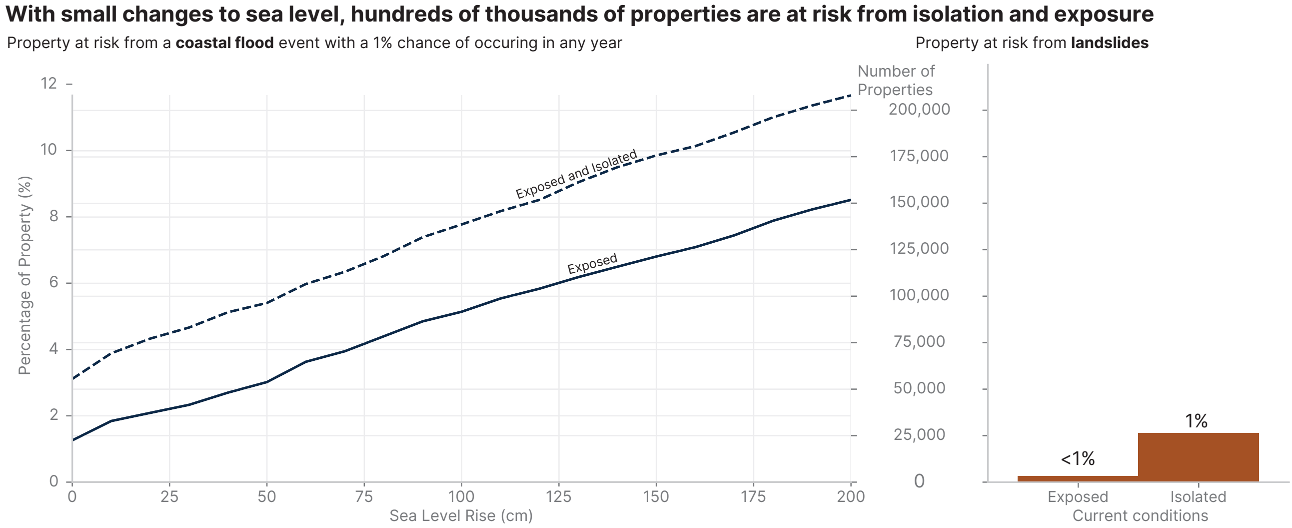
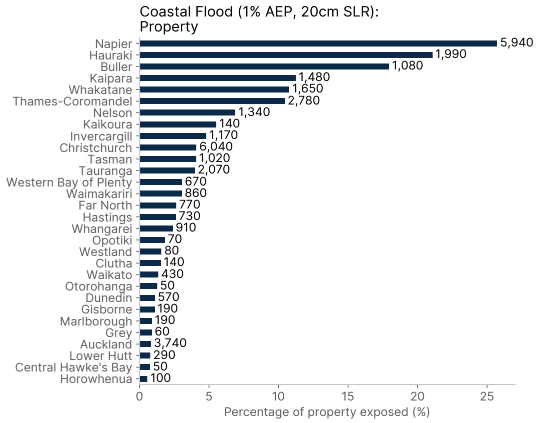


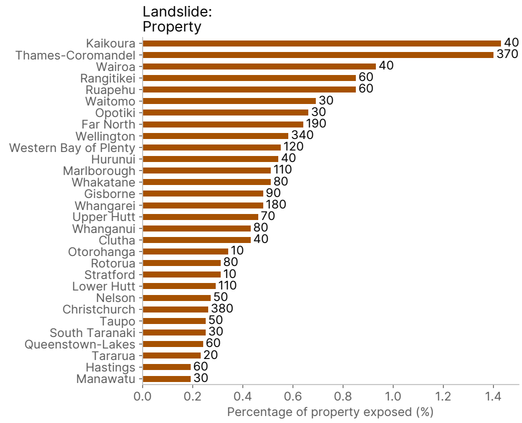
Figure 11: The risk of isolation and exposure from coastal flooding and landslides to property.

Figure 13 projects how property exposure and isolation risk from coastal flooding may change over time. By 2150, under the SSP1-2.6 scenario, exposure could reach 45% of properties in Napier, 30% in Buller, and 20% in Hauraki. Isolation risk could affect nearly 50% of properties in Napier, 40% in Thames-Coromandel, and 40% in Buller.

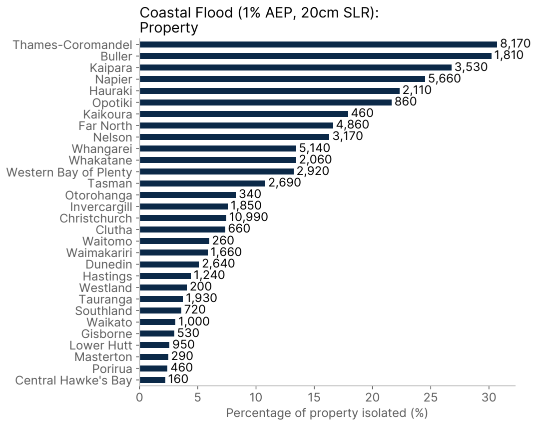
These projections are pertinent given recent research on insurance retreat. As sea level rise changes inundation frequency, 99% of properties currently within 1% AEP coastal inundation zones (approximately over 22,000 properties, 1.2%) may face partial insurance retreat within a decade, with full retreat likely within 20-25 years [6]. This number will increase in subsequent decades as more properties become exposed, underscoring the urgency of addressing these risks.



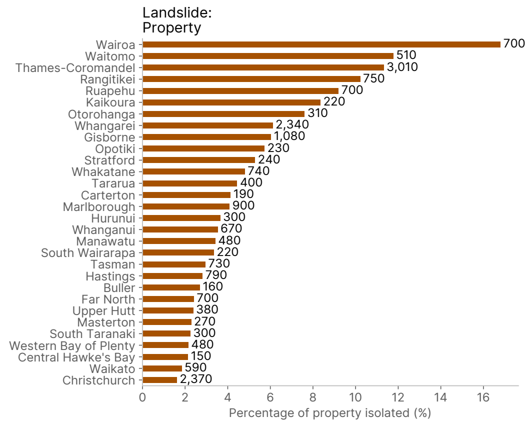
(a) Properties exposed to coastal flooding



(b) Properties exposed to landslides

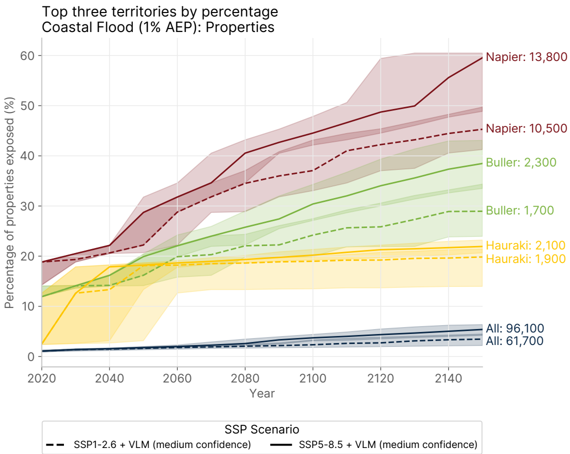


(c) Properties at risk from isolation due to coastal flooding

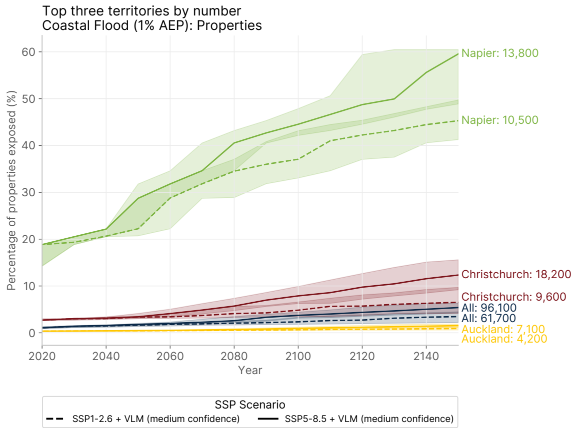


(d) Properties at risk from isolation due to landslides

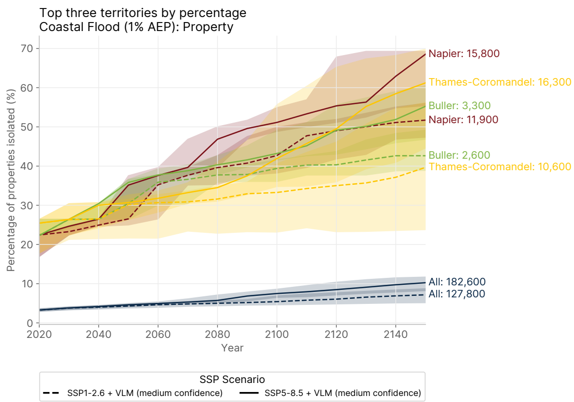
Figure 12: The exposure and isolation of properties to coastal flooding and landslides in New Zealand, ranked by the percentage of properties affected. The 30 most exposed or isolated districts, by percentage, are shown.



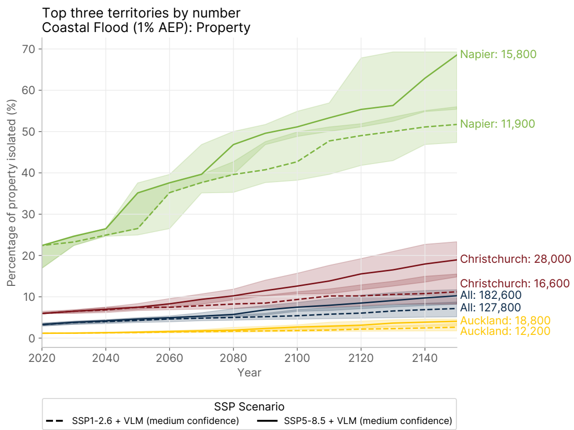
(a) Exposure by percentage (properties)



(b) Exposure by total number (properties)



(c) Isolation by percentage (properties)



(d) Isolation by total number (properties)

Figure 13: This figure shows how the exposure and isolation risks to properties from coastal flooding (with a 1% annual exceedance probability) are expected to change with relative sea-level rise. The top row displays exposure data, while the bottom row displays isolation data.

3.2 Linear Transport

Linear transport infrastructure, including roads, bridges, and rail, faces significant risks from natural hazards, with climate change expected to exacerbate these risks. The National Climate Change Risk Assessment has identified the risk to linear transport as *extreme*.

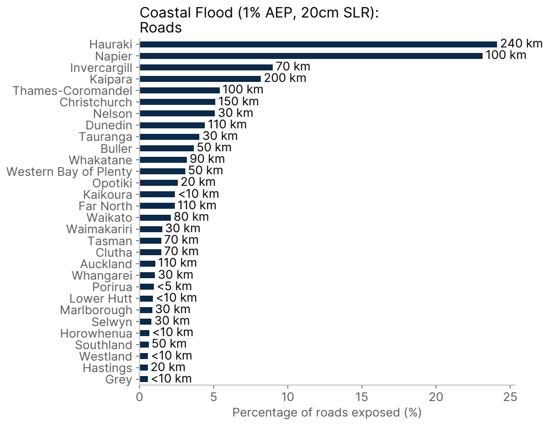
The vulnerability of the transport sector has wide-ranging implications. Road and rail networks are essential for moving people and goods across New Zealand and providing access to critical utilities such as airports, ports, and power or water infrastructure. Disruption or damage to these networks can isolate people from essential services and amenities.

Our analysis indicates the following exposure:

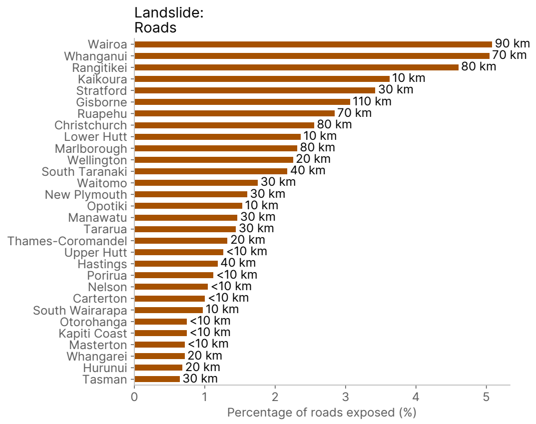
- Roads:
  - With 20cm of sea-level rise (SLR), nearly 2,000km of roads (1.4% of the national network) are exposed to 1% AEP coastal flooding.
  - This exposure increases to 3,600km (2.6%) with 1m of SLR.
  - Approximately 1,200km (0.9%) are exposed to landslides.
- Bridges:
  - More than 1,000 bridges (8%) are exposed to coastal flooding with 20cm of SLR.
  - This increases to 1,600 bridges (10%) with 1m of SLR.
  - Approximately 130 bridges (0.8%) are exposed to landslides.
- Rail:
  - 60km (1.5%) of rail is exposed to coastal flooding with 20cm of SLR.
  - This increases to 150km (3.7%) with 1m of SLR.

The risk from coastal flooding rises with sea level, as illustrated in Figures 14 and 15. Napier, Christchurch, Hauraki, Kaipara, and Invercargill are among the most exposed districts in terms of roading infrastructure.

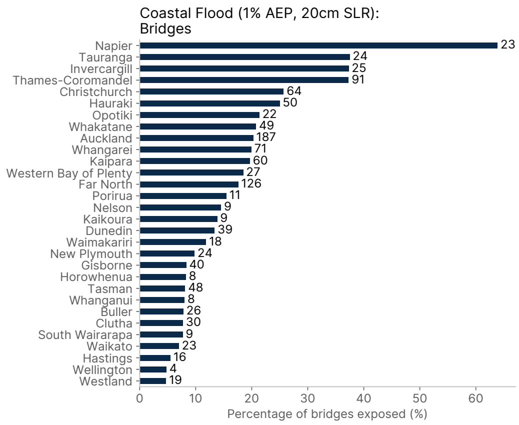
While the presence of bridges in flood zones is expected, the experience of Cyclone Gabrielle highlighted the vulnerability of our road network to bridge failure. This underscores the need for targeted adaptation strategies and monitoring of bridge infrastructure in flood-prone areas.



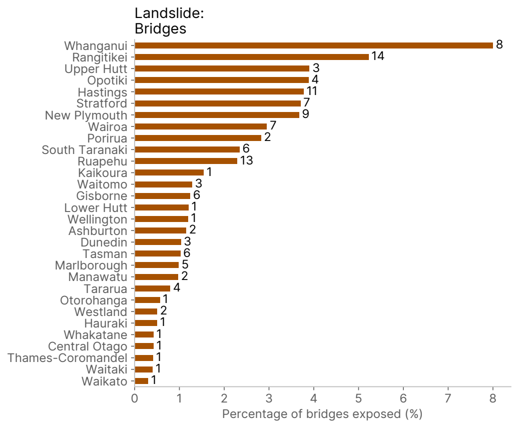
(a) Roads exposed to coastal flooding



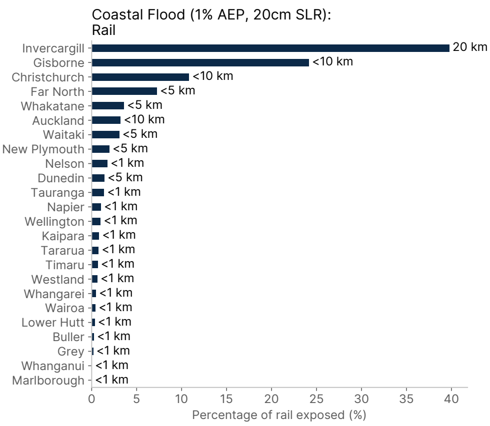
(b) Roads exposed to landslides



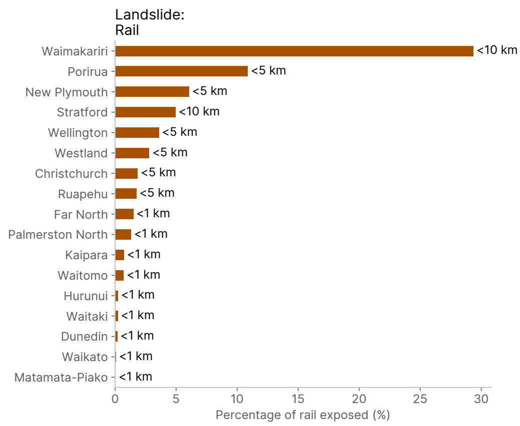
(c) Bridges in coastal flooding zones



(d) Bridges exposed to landslides

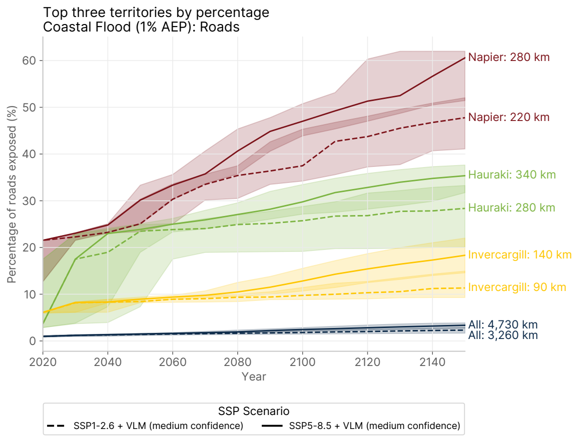


(e) Rail exposed to coastal flooding

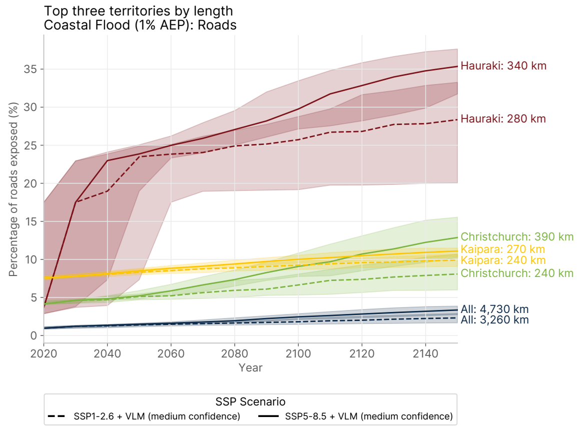


(f) Rail exposed to landslides

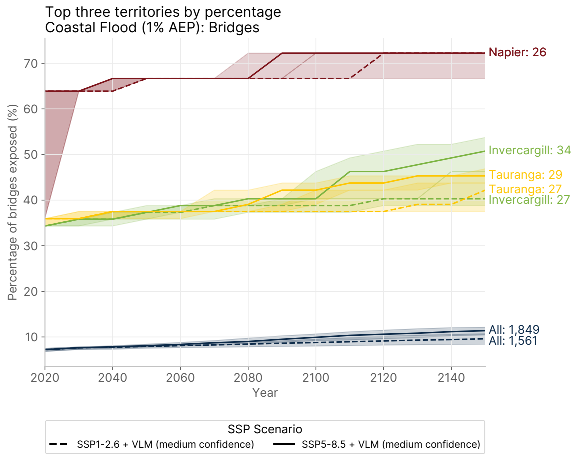
Figure 14: The exposure of linear transport infrastructures (roads, bridges, and rail) to coastal flooding and landslides in New Zealand, ranked by the percentage of infrastructure exposed.



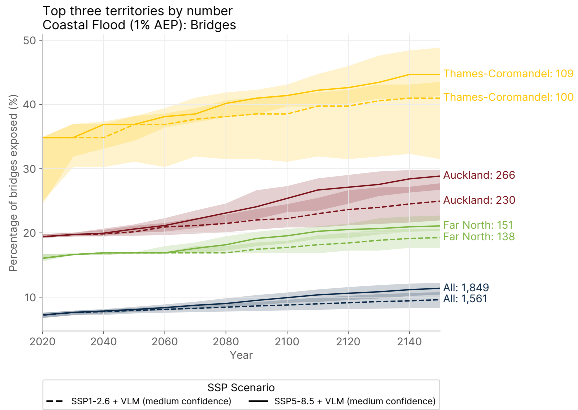
(a) Roads exposure by percentage



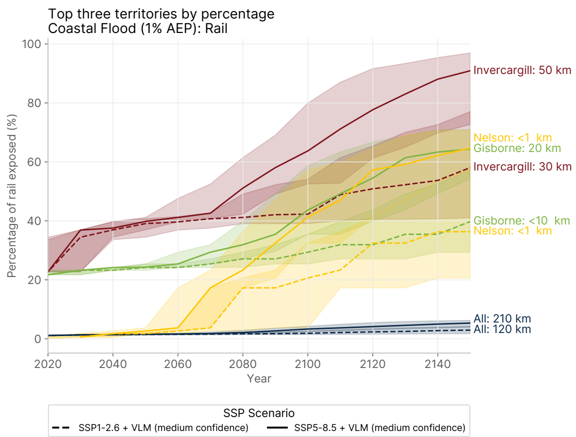
(b) Roads exposure by value



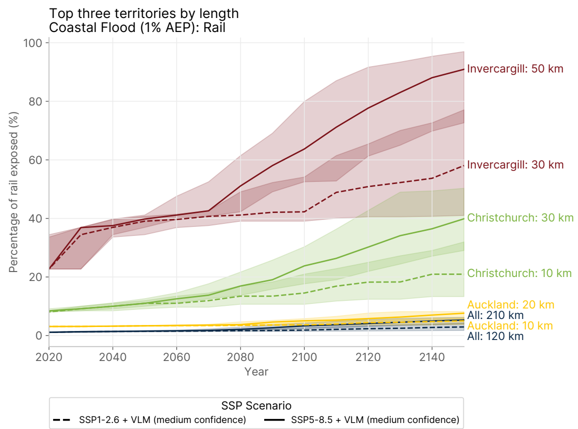
(c) Bridges exposure by percentage



(d) Bridges exposure by value



(e) Rail exposure by percentage



(f) Rail exposure by value

Figure 15: This figure shows how the exposure of roads, bridges, and rail infrastructure to coastal flooding (with a 1% annual probability) is expected to change with relative sea-level rise. Each row displays the exposure for New Zealand and the top three territories by percentage (left) and by the total length or number of exposed elements (right).

3.3 Essential Services

Access to essential services such as education, healthcare, and emergency response is fundamental to the day-to-day functioning and well-being of communities. These services form the backbone of societal infrastructure, supporting public health, safety, and social equity. However, climate change-induced hazards pose significant risks to both the physical infrastructure of these services and the ability of residents to access them.

The impacts of disruptions to these essential services can be far-reaching and long-lasting. For example:

- Education: Disruptions to schooling can lead to long-term learning losses, widening achievement gaps and exacerbating existing educational inequities. This is particularly concerning for vulnerable or disadvantaged students who may have fewer resources to compensate for lost instructional time.
- Healthcare: Reduced access to healthcare facilities can result in delayed treatments, poorer health outcomes, and increased stress on individuals and families. In emergency situations, such as during extreme weather events, the inability to reach hospitals could have life-threatening consequences.
- Emergency Services: Limitations on emergency services, such as fire stations, can significantly impair response times during critical situations. This puts lives and property at greater risk, especially in areas prone to natural hazards or accidents.

This analysis considers both the direct exposure of critical service facilities (schools, hospitals, and fire stations) to hazards, as well as the isolation risk faced by residents to these facilities. It is important to note that the facility-specific exposure results likely present an overestimate of risk, as many of these facilities have likely undertaken strengthening or risk-reducing actions that increase their ability to operate during natural hazard events. However, the isolation estimates provide a more comprehensive assessment of how hazards threaten the operation of these essential services.

3.3.1 Schools

Schools serve multiple community functions beyond education. They are centers for social development, often act as emergency shelters during disasters, and serve as community hubs. The impacts of climate change on school infrastructure and accessibility can have profound and far-reaching consequences for student learning, well-being, and long-term societal outcomes.

Our analysis finds significant exposure and isolation risks to schools across New Zealand:

Exposure:

- Nationwide, 106 schools are exposed to a 1% Annual Exceedance Probability (AEP) coastal flood with 20cm of sea-level rise.
- Auckland faces the highest absolute risk, with 21 schools exposed, followed by Christchurch (11) and Napier (9).
- In relative terms, Buller is most at risk with over 50% of its schools exposed, while Thames-Coromandel and Hauraki both have more than 30% of their schools at risk (Figure 16a).

- Landslides pose a comparatively lower direct risk, with only 8 schools exposed nationwide (Figure 16b).

Isolation:

- Approximately 150,000 people across the country are at risk of being unable to access schools due to a 1% AEP coastal flood with 20cm of sea-level rise.
- An additional 50,000 people face potential isolation from schools due to landslides.
- Thames-Coromandel (39%), Kaipara (35%), and Buller (31%) have the highest percentage of residents at risk of losing access to schools due to coastal flooding.
- In absolute numbers, Napier (>16,000), Christchurch (>21,000), and Auckland (>15,000) have the most residents at risk of school isolation.

Future Projections: By 2150, the number of people at risk of losing access to schools could increase to more than 250,000 nationwide, including more than 40% of the residents of Thames-Coromandel, Buller, and Napier (Figures 18a and 18b).

3.3.2 Fire Stations

Access to and from fire stations means that emergency services can respond to fires, accidents, and other life-threatening situations. Impacts to fire station infrastructure and access compromises the ability of emergency/first responders to provide timely assistance.

Exposure:

- 15 fire stations nationwide are exposed to a 1% Annual Exceedance Probability (AEP) coastal flood with 20cm of sea-level rise (Figure 16c).
- Hauraki and Waimakariri districts each have two exposed fire stations, the highest number per district.
- With 1m of sea-level rise, the number of exposed fire stations increases to 38 nationwide for a 1% AEP flood event.
- In this scenario, Christchurch has five exposed stations, while Thames-Coromandel and Waimakariri each have three.
- 24 fire stations are exposed to landslides across the country (Figure 16d).
- Christchurch has the highest landslide exposure with three stations, while Far North, Hauraki, Kaipara, and Waimakariri each have two exposed stations.

Isolation:

- Approximately 150,000 people (3% of the population) are at risk of isolation from fire stations due to 1% AEP coastal flooding with 20cm of sea-level rise.
- An estimated 50,000 people (1% of the population) are at risk of isolation from fire stations due to landslides.
- Thames-Coromandel, Buller, and Hauraki have the highest percentage of their populations at risk of isolation.
- Christchurch, Napier, and Auckland have the highest number of residents at risk of isolation (Figure 18).

Future Projections: Projections indicate that by 2150, as many as 400,000 people nationwide could be at risk of isolation from fire stations (Figures 18c and 18d).

3.3.3 Hospitals

Healthcare infrastructure and its accessibility are key components of community resilience. This analysis examines both the direct exposure of hospitals to natural hazards and the potential isolation of residents from hospital services.

Exposure:

- Six hospitals nationwide are exposed to a 1% Annual Exceedance Probability (AEP) coastal flood with 20cm of sea-level rise (Figure 16e).
- Based on the available data, no hospitals are directly exposed to landslides (Figure 16).

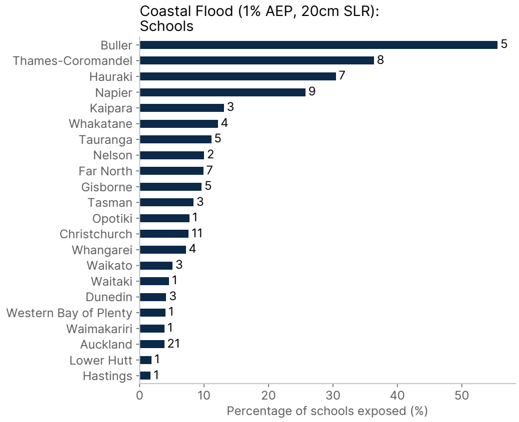
Isolation:

- Coastal flooding with 20cm sea-level rise (1% AEP event):
  - Approximately 213,000 people (5% of the national population) are at risk of isolation from hospitals.
  - Districts with the highest percentage of population at risk include:
    - Thames-Coromandel: 84% (25,000 people)
    - Kaipara: 40% (9,200 people)
    - Buller District: 31% (3,000 people)
  - Districts with the highest number of people at risk:
    - Christchurch: 24,800 (7% of the population)
    - Auckland: 33,800 (2% of the population)
    - Thames-Coromandel
- Landslide risk:

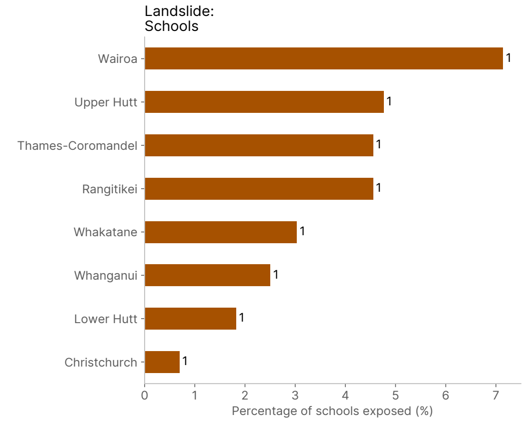
- More than 90,000 people (2% of the national population) are estimated to be at risk of isolation from hospitals.
- Districts with the highest percentage of population at risk include:
  - Thames-Coromandel: 57% (17,000 people)
  - Wairoa: 31% (2,600 people)
  - Ruapehu: 24% (2,900 people)
- Districts with the highest number of people at risk:
  - Thames-Coromandel: 17,000 (57% of the population)
  - Christchurch: 8,000 (2% of the population)
  - Gisborne: 7,800 (16% of the population)

Future Projections: Under continued sea level change scenarios, the number of residents at risk of isolation from hospitals is projected to increase:

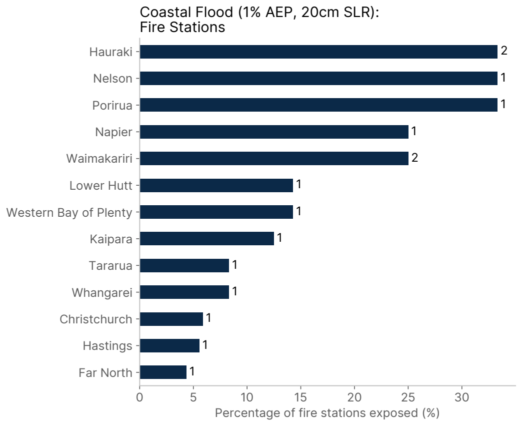
- By 2150, between 350,000 and 515,000 residents could be at risk of isolation due to coastal flooding (Figure 18e).



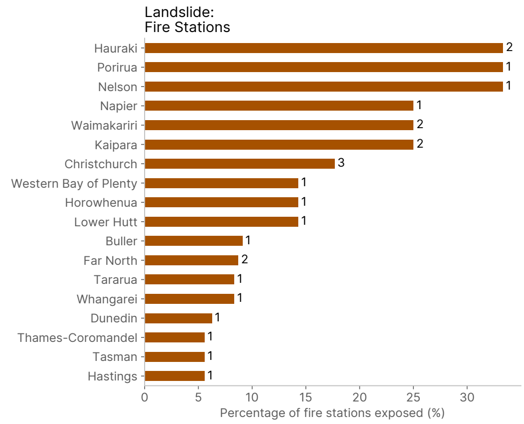
(a) Schools exposed to coastal flooding



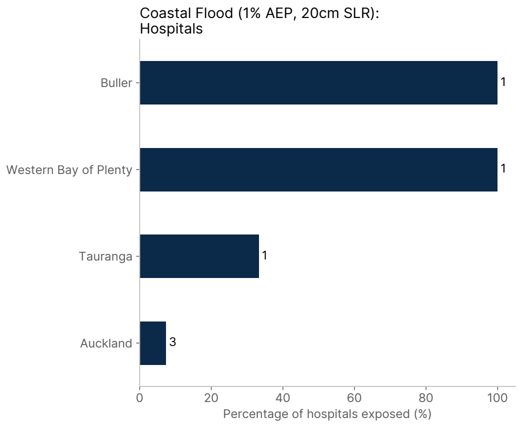
(b) Schools exposed to landslides



(c) Fire stations exposed to coastal flooding

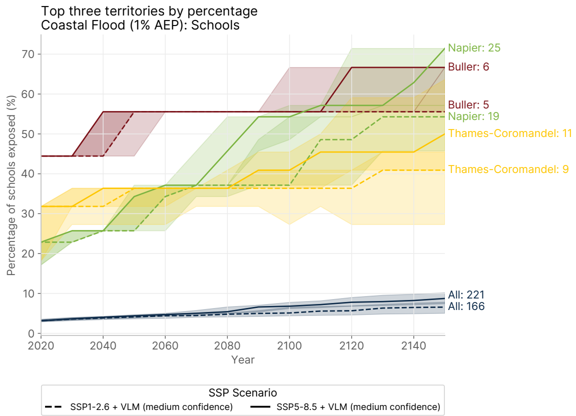


(d) Fire stations exposed to landslides

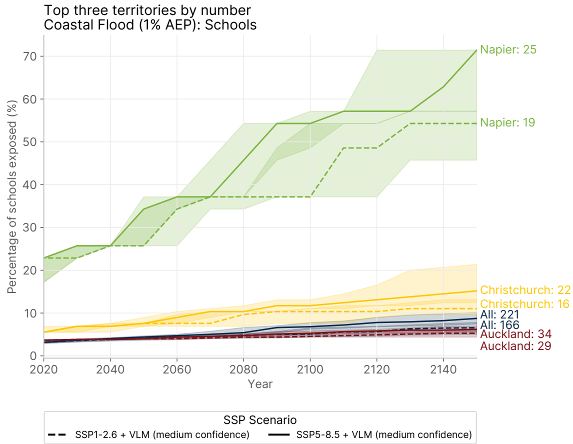


(e) Hospitals exposed to coastal flooding

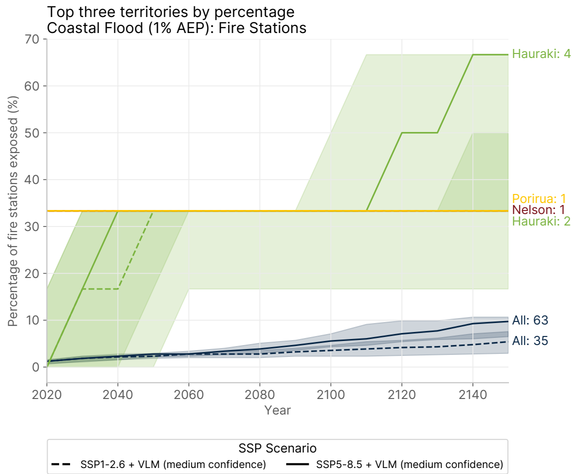
Figure 16: The exposure of essential infrastructure services (schools, fire stations, and hospitals) to coastal flooding and landslides in New Zealand, ranked by the percentage of infrastructure exposed. Note that there is no known exposure of hospitals to landslides.



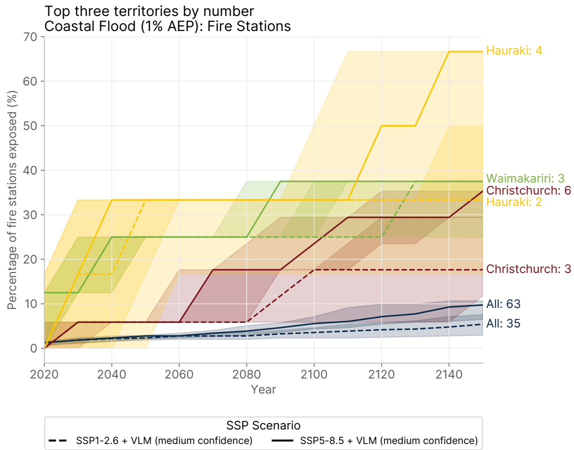
(a) Schools exposure by percentage



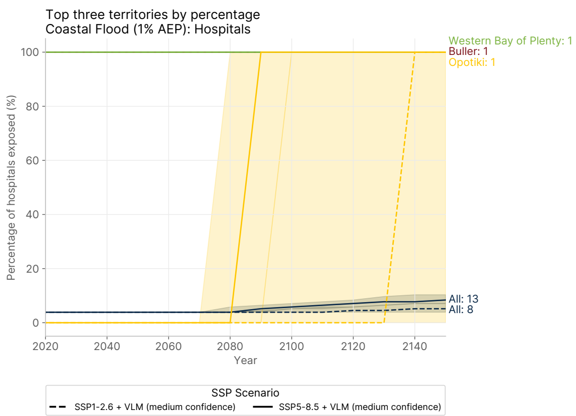
(b) Schools exposure by value



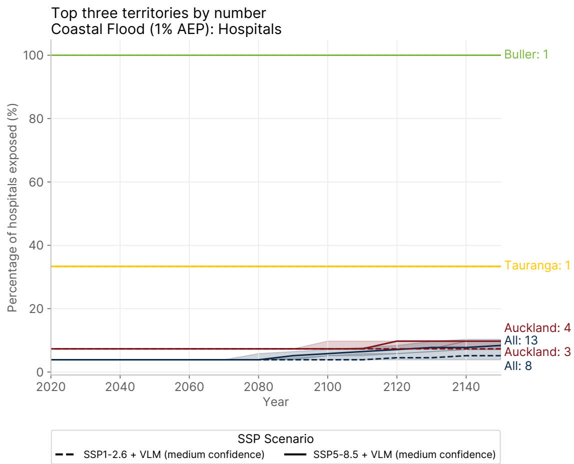
(c) Fire stations exposure by percentage



(d) Fire stations exposure by value

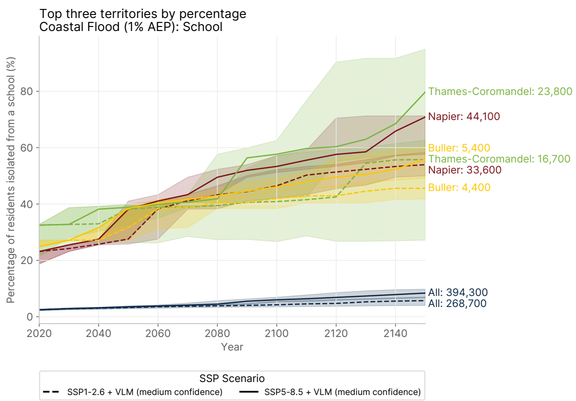


(e) Hospitals exposure by percentage

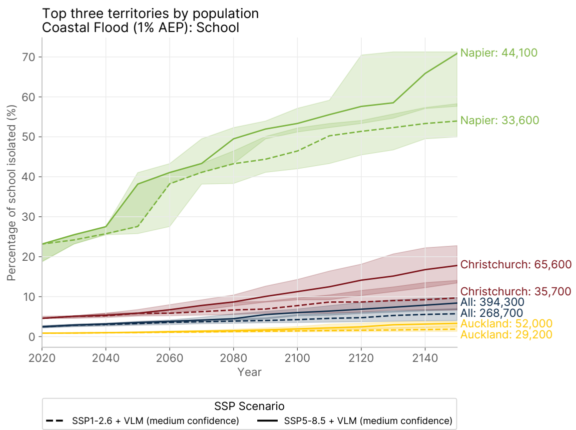


(f) Hospitals exposure by value

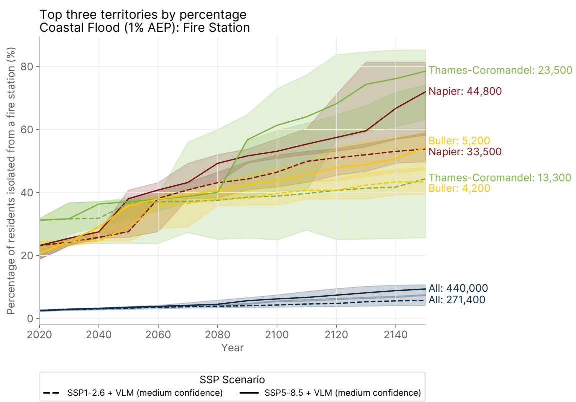
Figure 17: This figure shows how the exposure of schools, fire stations, and hospitals to coastal flooding (with a 1% annual probability) is expected to change with relative sea-level rise. Each row displays the exposure for New Zealand and the top three territories by percentage (left) and by the total number of exposed elements (right).



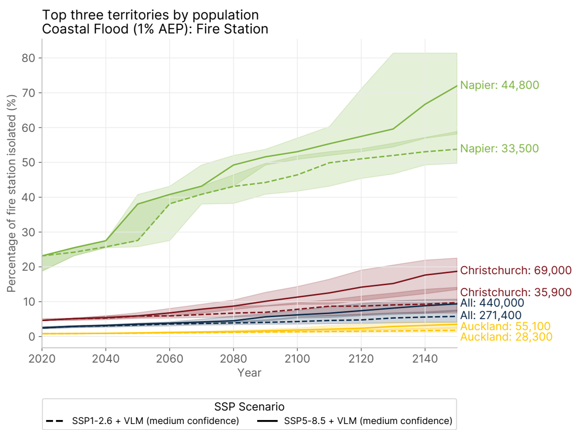
(a) Risk of isolation from schools by percentage



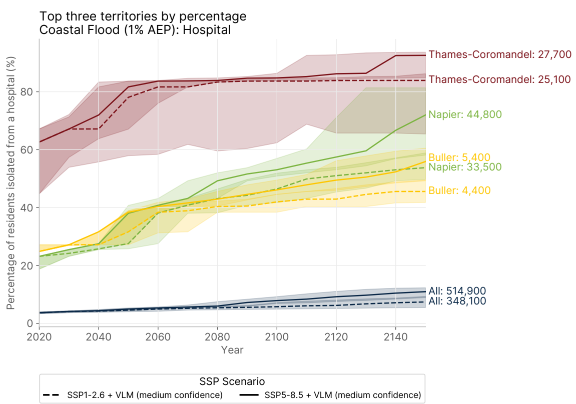
(b) Risk of isolation from schools by value



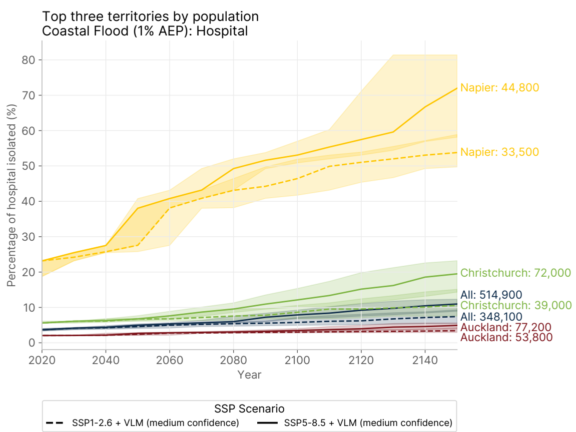
(c) Risk of isolation from fire stations by percentage



(d) Risk of isolation from fire stations by value



(e) Risk of isolation from hospitals by percentage



(f) Risk of isolation from hospitals by value

Figure 18: This figure shows how the risk of isolation to schools, fire stations, and hospitals due to coastal flooding (with a 1% annual probability) is expected to change with relative sea-level rise. Each row displays the exposure for New Zealand and the top three territories by percentage (left) and by the total number of exposed elements (right).

3.4 Marae

Marae are cornerstone cultural, social, and spiritual centers for Māori communities, serving as the heart of Māori cultural identity and connection to whenua (land). Beyond their cultural significance, marae play an important role in community resilience, often functioning as emergency hubs and refuges during extreme weather events and other crises. This dual function makes marae essential not only for preserving Māori traditions and practices but also for supporting the broader community's ability to withstand and recover from disasters. However, the location of many marae in coastal regions and near rivers exposes them, and their access, to increasing risks from flooding, coastal erosion, and landslides. Climate change impacts on marae infrastructure and access can have far-reaching consequences, potentially compromising both cultural continuity and community-wide disaster response capabilities. The isolation of marae from the communities they serve could significantly undermine local resilience, especially in situations where other emergency services and essential infrastructure are also disrupted. Moreover, the cultural, social, and spiritual wellbeing of Māori communities could suffer if ancestral marae and surrounding sites of significance like urupa (burial grounds) and mahinga kai (food gathering areas) are damaged or destroyed by climate change impacts, further emphasising the critical importance of protecting these cultural keystone sites.

For example, in the Tairāwhiti rainfall event in March 2022, Anaura Bay – a coastal community with a high Māori population – was cut off due to widespread flooding and road slips. Hinetamatea marae suffered significant damage and part of the urupā was washed out to sea. Similar stories have been seen in other remote communities such as Mohaka, Raupunga, Tolaga Bay, the Waikato, and the Wairua Lagoons, where road closures, power cuts, kaimoana contamination, and displacement have occurred.

Figure 19 shows isolation and exposure risk for marae from coastal flooding, with changing sea level, and landslides. This illustrates the magnitude in both number and percentage of marae that are currently burdened and could be burdened in the future.

Nationwide, 116 marae (11%) are at risk of isolation from a 1% AEP coastal flood with 20cm of sea-level rise, while 88 marae (8%) are at risk of isolation due to landslides (Figure 20). In comparison, direct exposure affects fewer marae: 14 marae (~1%) are exposed to coastal flooding with 20cm of sea-level rise, and only 2 marae (<1%) are exposed to landslides.

With 20cm of sea level rise, expected to occur within a few decades under most climate change scenarios, the Far North District faces the highest number of marae at risk of isolation (34, 24%). For landslides, Whanganui District has the highest number of marae at risk of isolation (17, 52%), followed by Gisborne (13, 18%) and Wairoa (8, 20%).

Figure 20f illustrates how marae isolation risk from coastal flooding is projected to change over time with sea level rise. Kaipara, Far North, and Auckland have the highest number of marae threatened with isolation from coastal flooding. By 2150, there is the potential for 10, 45, and 11 marae respectively to be isolated in each of these districts.

The high risk of isolation compared to direct exposure emphasises that adaptation strategies must prioritise maintaining connectivity to marae, even when the sites themselves may not be directly impacted by flooding or landslides. This isolation could prevent marae from fulfilling their vital roles as cultural centers and emergency hubs during disasters, potentially compromising both cultural continuity and community resilience.

Isolation has the potential to burden more marae than direct exposure to the hazard

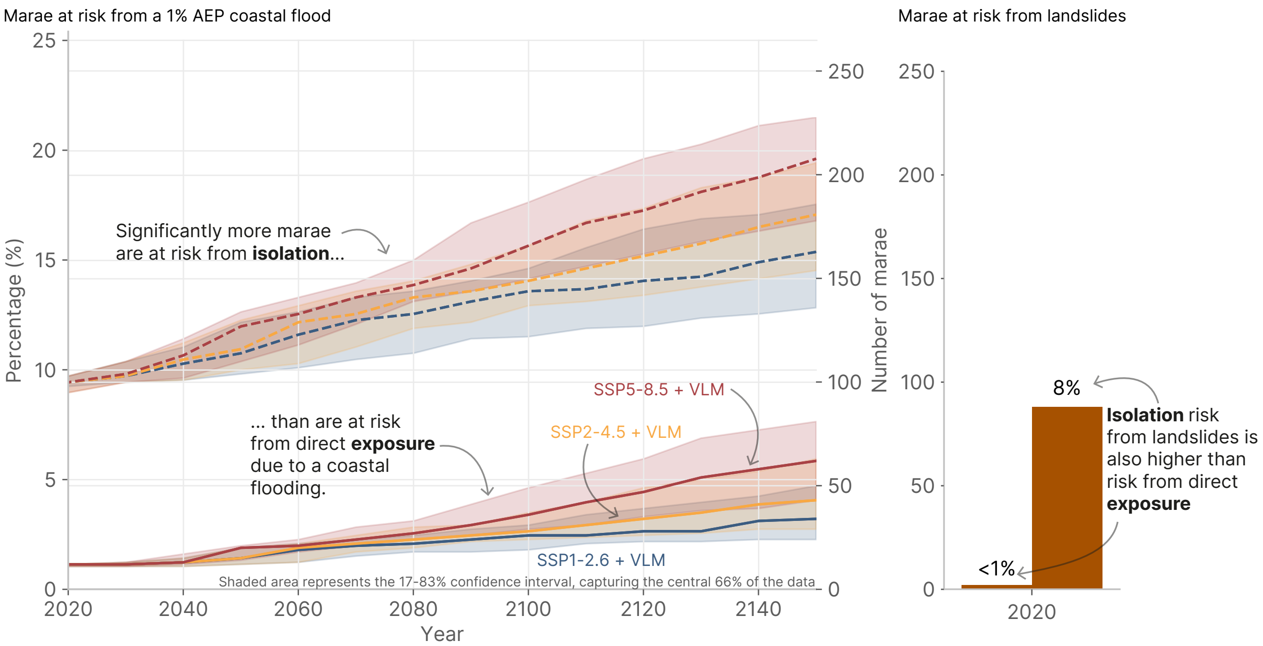
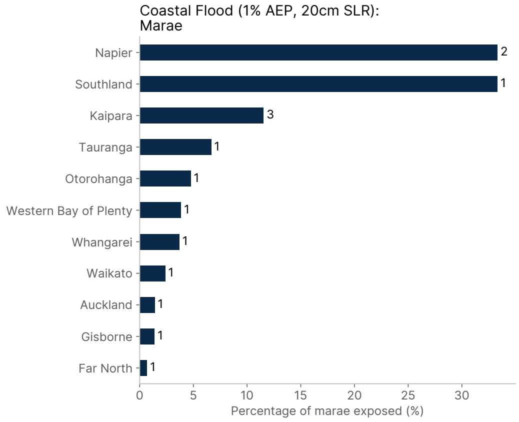
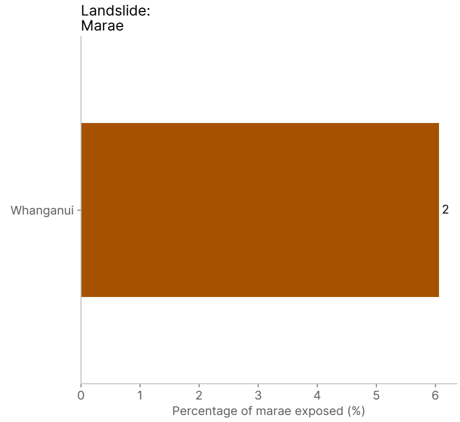


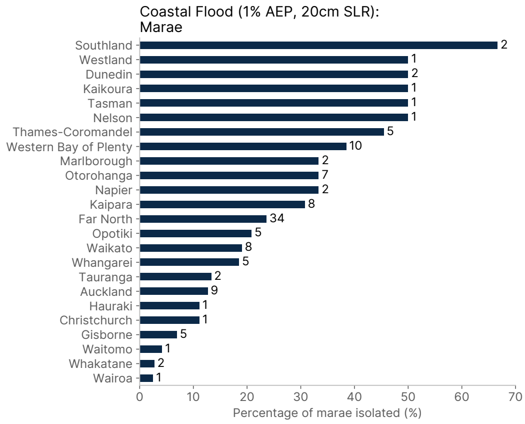
Figure 19: The risk of isolation and exposure from coastal flooding and landslides to marae.



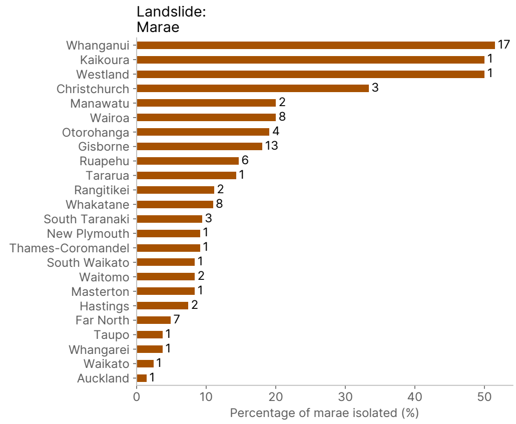
(a) Coastal flood exposure



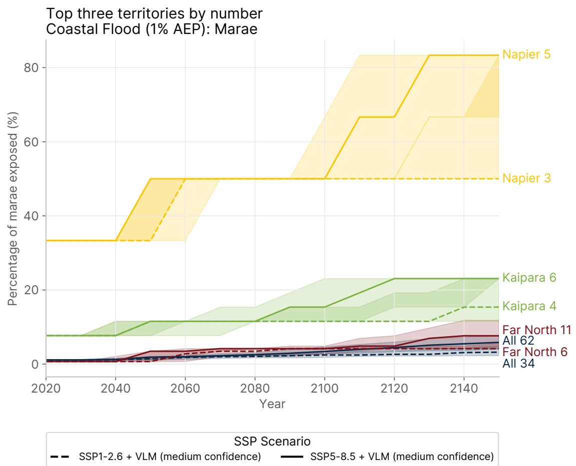
(b) Landslide exposure



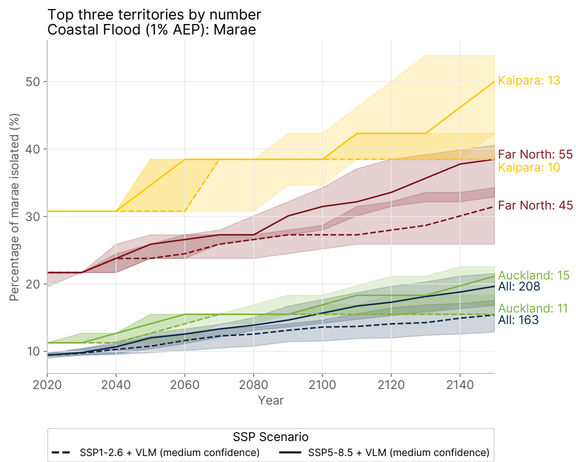
(c) Coastal flood isolation



(d) Landslide isolation



(e) Exposure over time



(f) Isolation over time

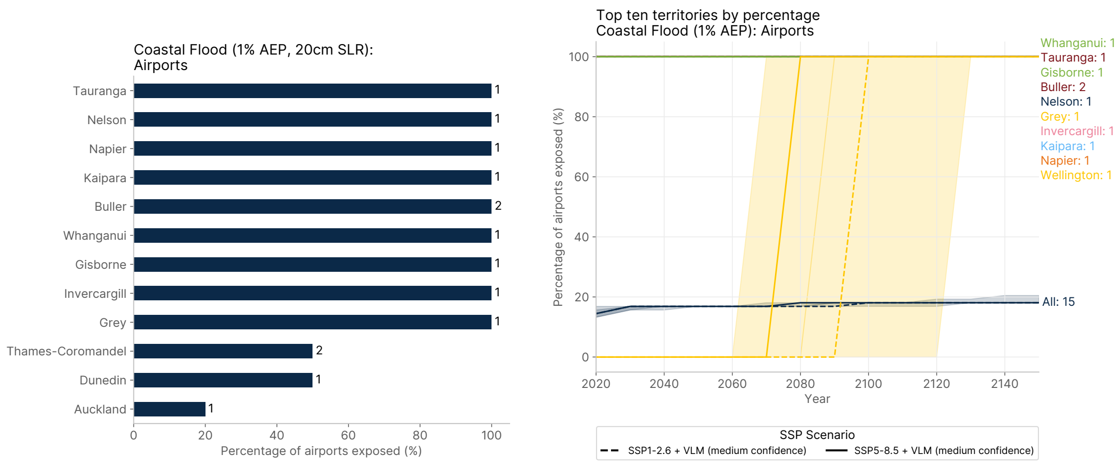
Figure 20: The exposure and risk of isolation to marae from coastal flooding and landslides in New Zealand, ranked by the percentage of marae exposed. The last row shows the changes in risk of flooding and isolation over time with relative sea-level rise.

3.5 Airports

Airports are critical infrastructure assets that serve as lifeline utilities, as identified under the 2002 Civil Defence Emergency Management Act. They play a vital role in the well-being and connectivity of communities, facilitating transportation, tourism, and economic activities. Often co-owned by the private sector, central government, and local authorities, airports are essential for both day-to-day operations and emergency situations.

The National Climate Change Risk Assessment classified airport risk as "Extreme" due to projected changes in temperature, wind, and extreme weather events [4]. Other hazards include inland and coastal flooding and coastal erosion. As shown in Figure 21a, 14 of New Zealand's airports are threatened by coastal flooding with 20cm of sea-level rise, including those in Buller, Gisborne, Grey, Invercargill, Kaipara, Napier, Nelson, Tauranga, and Whanganui. Furthermore, Figure 21b illustrates that a significant number of airports across the country are already at risk of a 1% coastal flood event. The severity of this exposure will increase with sea level rise, meaning additional action will be required to mitigate it. This risk has far-reaching implications for New Zealand's economy and society. Damage to airport infrastructure and assets, as well as compromised operations due to extreme weather and flooding, could lead to cascading impacts on various sectors, including tourism. The networked nature of airports to the surrounding infrastructure, both domestically and internationally, further amplifies the consequences of these risks. Regional economies are particularly vulnerable, as the data suggest, with many regions having all of their airports at risk of coastal flooding.

It is important to note that this analysis does not consider existing protective measures such as stop-banks or engineered stormwater systems. However, given the proximity of many airports to the coast, it is crucial that airport authorities are aware of the potential impact of sea-level-induced changes in groundwater levels on their runway pavements [19]. Site-specific analysis for each airport would provide greater confidence in their individual situations and inform the development of appropriate management plans.



(a) Airports exposed to coastal flooding by Territorial Authority. Note that there is no known exposure of airports to landslides.

(b) How the exposure of airports to coastal flooding (with a 1% annual probability) is expected to change with relative sea-level rise. This shows the ten territories that have all of their airports exposed.

Figure 21: Exposure of airports by Territorial Authority.

3.6 Transmission Structures

The National Transmission Grid transmits electricity from generation sites to electricity distribution networks and some major consumers supplied directly from the grid. The most critical components of the transmission and distribution network are generally those that transmit the largest volume of electricity, have limited redundancy, or supply critical customers.

As identified in the National Climate Change Risk Assessment, climate change presents a range of risks for New Zealand's electricity transmission and local distribution infrastructure. These mainly relate to changes in temperature, rainfall, snow, extreme weather events, wind, and fire weather. Other hazards include inland and coastal flooding.

In this analysis, transmission structures constitute all Transpower structures, towers, and pole center points. The data reveals the following exposure:

- Coastal flooding with 20cm sea-level rise (1% AEP event):
  - 79 out of 38,089 transmission structures (0.2%) nationwide are exposed.
  - Ōpōtiki District has the highest percentage of exposed structures (10.5%, 4 out of 38).
  - Auckland has the highest number of exposed structures (41), representing 2.3% of its total.
- Landslide risk:
  - 513 transmission structures (1.4% of the national total) are exposed to landslide-prone areas.
  - Wairoa District has the highest percentage of exposed structures (11.5%, 26 out of 227).
  - Ruapehu District has the highest number of exposed structures (79), representing 8.9% of its total.

With 1m of sea-level rise, the number of transmission structures exposed to coastal flooding increases to 213 (0.6% of the national total).

Depending on the type of structure, small levels of coastal flood exposure may not cause damage or disruption at the infrastructure site but may instead challenge access and maintenance. Although not included in this study, risk of isolation to transmission assets may provide further information to support adaptation planning.

These findings underscore the need for targeted adaptation strategies for transmission infrastructure, particularly in areas prone to landslides and coastal flooding. While the percentage of exposed structures is relatively low nationally, certain districts face significantly higher risks, which could have implications for local and regional energy security.

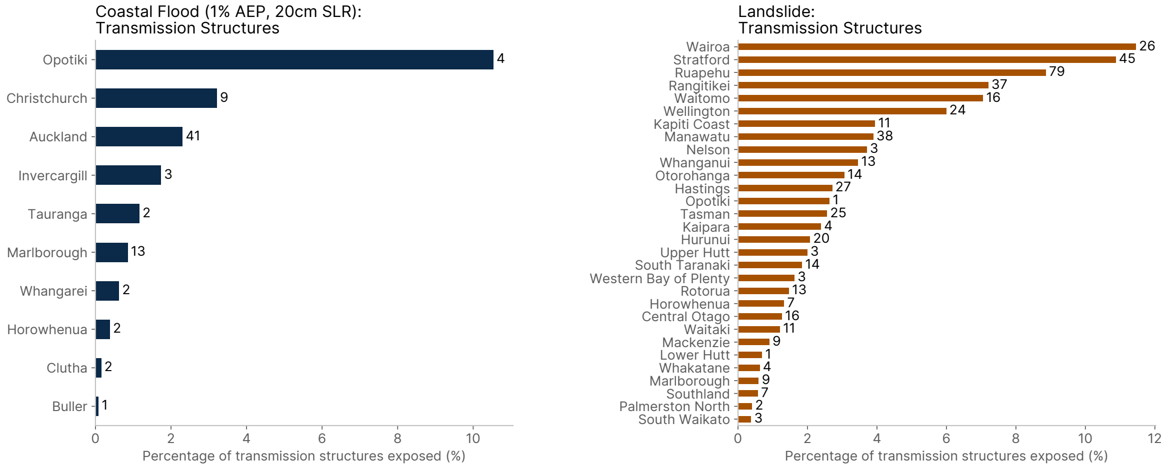


Figure 22: The exposure of transmission structures to coastal flooding and landslides in New Zealand, ranked by the percentage of transmission structures exposed.

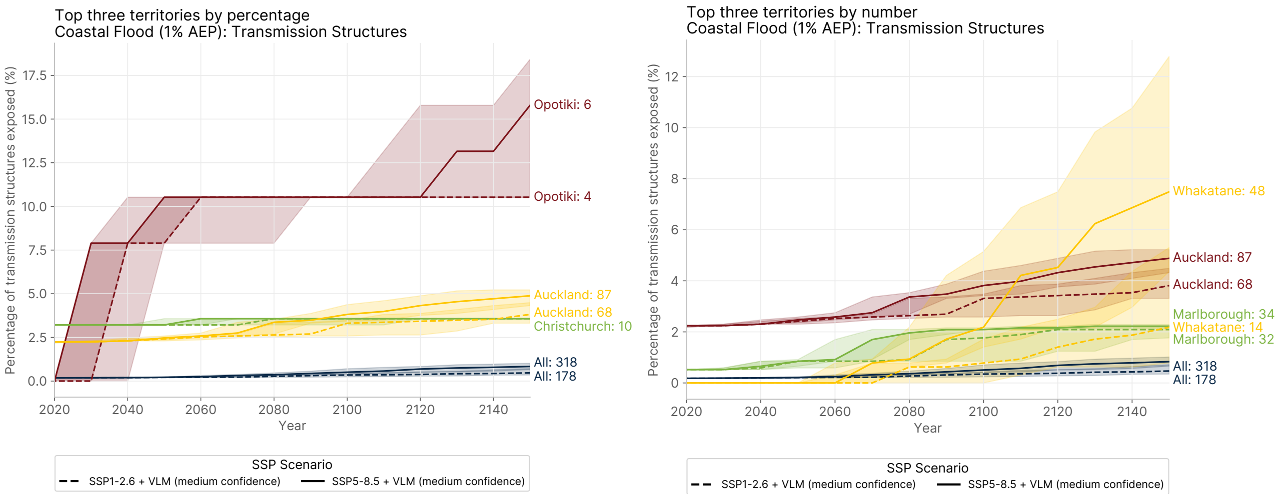


Figure 23: How exposure of transmission structures to coastal flooding (with a 1% annual probability) is expected to change with relative sea-level rise. The left figure displays the exposure for New Zealand and the top three territories by percentage, while the right figure shows the top three territories by the total length of exposed elements.

4 Results: People and Demographic Groups

Understanding the characteristics of people at risk means that effective response and adaptation strategies can be designed. These characteristics may influence how different groups are affected by hazards, how they perceive and understand risks, and what types of risk mitigation actions are most appropriate or effective for them. It is important to note that these characteristics do not inherently indicate vulnerability; rather, they provide context for developing more appropriate adaptation strategies.

Overall, more than 140,000 New Zealanders (over 3% of residents) are at risk of isolation from a 1% AEP coastal flood within the next 10-20 years (Figure 24). Currently, around 50,000 people are at risk of direct exposure to coastal flooding, a number projected to increase to between 100,000-300,000 by 2150, depending on the sea-level rise scenario. For landslides, approximately 1% of the population is at risk of both isolation and direct exposure.

When examining the risk by ethnicity, Māori and European/Other face the highest percentage risk of isolation from both landslides and coastal flooding. For coastal flooding with 20cm sea-level rise and 1% AEP, around 4% of Māori (29,300 individuals) and European/Other ethnic groups (122,600 individuals) are at risk of isolation. For direct exposure to coastal flooding there are approximately 14,300 Māori and 57,600 European/Other individuals at risk. The impact on Māori communities highlights the need for culturally appropriate and targeted adaptation strategies.

Household income levels also play a role in how people might be affected by these hazards. Lower-income households (earning 0-40,000 NZD annually) show the highest percentage risk of both exposure (2.5%) and isolation (4.4%) to coastal flooding. Middle-income households (40,000-90,000 NZD) follow closely, with 2% at risk of exposure and 4.1% at risk of isolation. These middle-income households also represent the largest numbers of residents affected. For landslides, middle-income households face the highest percentage isolation risk at 1.3%. Higher-income households generally face lower risks nationwide.

Finally, we examine the exposure and isolation risk by NZ Deprivation Index (NZDep2018). This index is an area-based measure of socioeconomic deprivation in Aotearoa New Zealand, based on nine Census variables. It categorises New Zealand into deciles, where decile 1 represents the least deprived areas and decile 10 the most deprived. It is important to note that NZDep estimates relative socioeconomic deprivation for areas, not individuals.

Analysis using the NZDep2018 reveals that there is a disproportionate number of people living in more deprived areas who are threatened by coastal flooding. In the most deprived areas (NZDep 9-10), 3% of people (29,500 individuals) are at risk of isolation and 1.6% (16,700) are at risk of direct exposure. Somewhat deprived areas (NZDep 7-8) show the highest percentage of people at risk of isolation (4.1%) and exposure (2.3%). In contrast, the least deprived areas (NZDep 1-2) have 2% (18,400) of residents at risk of isolation and only 0.6% (5,800) face direct exposure. For landslides, the isolation risk is more evenly distributed across deprivation levels, ranging from 0.7% to 1% of the population in each category.

These findings highlight the importance that adaptation strategies consider these and other socio-economic and demographic characteristics. Different groups may have unique strengths, coping mechanisms, or cultural practices that enhance their resilience. Considering these characteristics and the adaptive capacities of the areas and people affected will be important for finding equitable and effective interventions.

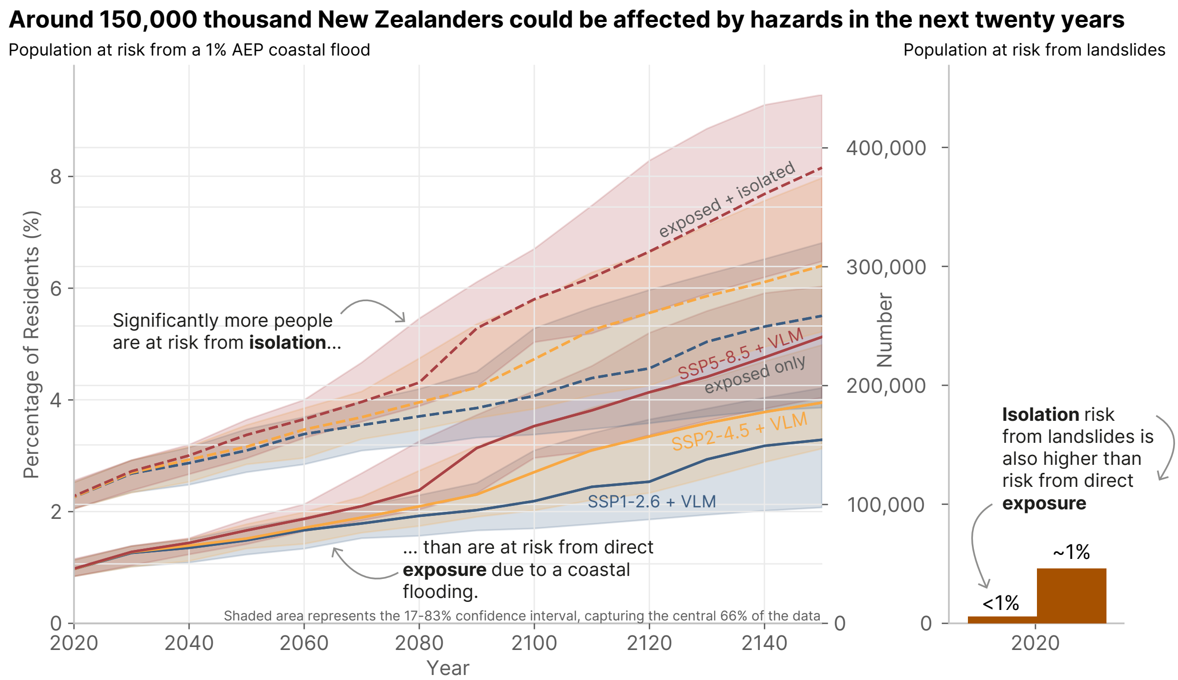


Figure 24: The risk of isolation and exposure from coastal flooding and landslides to New Zealanders.

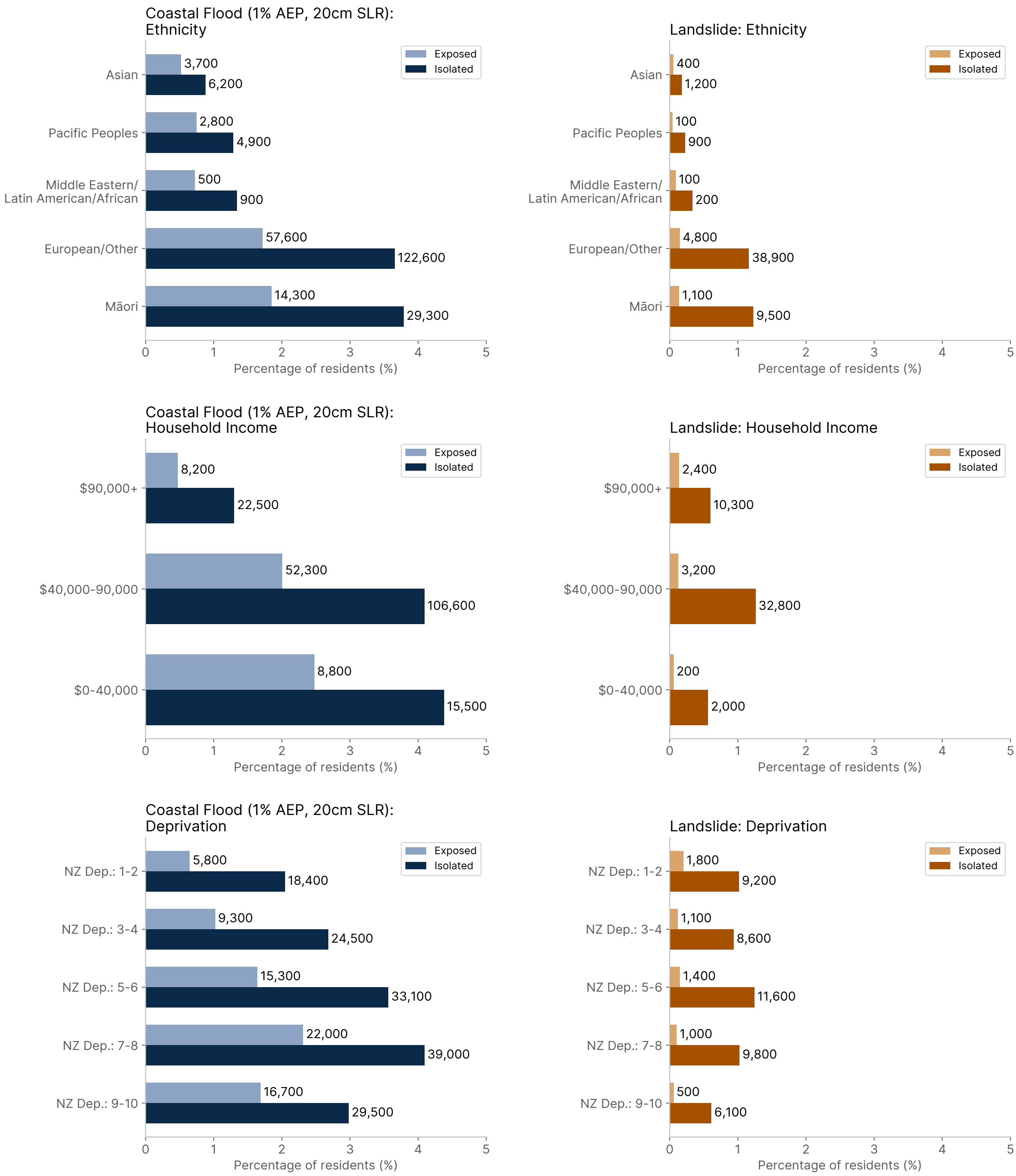


Figure 25: Risk of exposure and isolation arising from coastal flooding (20cm SLR, 1% annual exceedance probability) and landslides, categorised by socio-demographic groups. The results are plotted by percentage of the group and the approximate number of residents are annotated beside the bar.

5 Methodology

5.1 Method

5.1.1 Extent of Property and Infrastructure in At-Risk Areas

The first metric aims to estimate the number of property and infrastructure exposed to climate change. Exposure is where an asset is located within a hazard-prone area. This is calculated spatially by determining whether the asset intersects with the estimated hazard extent. For roads and rail the length of the exposed portion is reported, while the other assets are counted as exposed or not.

This metric quantifies exposure but does not assess the potential damage to assets resulting from the severity or intensity of that exposure. In other words, it does not consider the vulnerability of each asset — an exposed asset might be sufficiently robust to withstand a certain level of exposure without damage or disruption. A comprehensive risk assessment would typically include hazard-asset specific vulnerability functions to capture this aspect. However, such an analysis is beyond the scope of this work, primarily due to the unavailability of sufficiently detailed hazard datasets at a national scale.

5.1.2 Property and Marae at Risk of Isolation

Property and marae are considered at risk of isolation if no publicly accessible driving route exists between it and any sites of interest as a result of a hazard or natural event [8]. That is, a property is considered isolated if it does not have access to any fire stations, hospitals, or primary schools - these destinations represent key activity centres/facilities that provide or are collocated near opportunities and essential services for residents [20, 21, 22]. The road network is recompiled to exclude any road links, excluding bridges, that intersect the hazard extent; this is repeated for the different hazards and range of sea-level rise increments available [7]. That is, a road is considered impassable if there is exposure to any depth of flooding (i.e., impassable if depth $>$ 0cm) or extent of modelled landslide. If a destination intersects the extent of the hazard in question, it is considered closed/inoperable and, therefore, excluded as a viable destination in the access query. For the avoidance of doubt, destinations (e.g., a hospital) that are considered exposed and removed from the routing are still considered in the infrastructure exposure assessment.

To determine whether a path exists between origins and destinations we use the OpenSourceRoutingMachine (OSRM). This uses OpenStreetMap (OSM) road data to calculate the shortest network distance between any two given points (for further details [23]). If no possible route exists, this indicates that the origin is disconnected or isolated from the destination.

Once we have an estimate as to whether a household/parcel is isolated, then we integrate demographic information to estimate the distribution of burden across the population. We use dasymetric mapping to estimate the number of people in the property, based on the relative size of the property and the number of people in the finest resolution census reporting unit. This number is then used as a weighting to estimate the social/economic/demographic characteristics of the individuals affected. This is then reported by Territorial Authority.

5.1.3 Impacts over time

To understand how coastal flooding exposure and isolation risks evolve with rising sea levels, we combine our exposure and isolation results with climate change projections and vertical land movement data from the NZ SeaRise: Te Tai Pari O Aotearoa programme [17]. This programme has released location-specific sea-level rise projections out to the year 2300 for every 2 km of the coast of Aotearoa New Zealand, allowing us to estimate when impacts may occur under different sea-level rise scenarios.

Determining the timing of impacts:

For each asset or property, we identify the minimum sea-level rise value that results in its exposure or isolation. We associate each asset or property with the nearest NZ SeaRise projection site (based on Euclidean distance). For each sea-level rise projection, we determine the year when the asset or property reaches the sea-level rise value that results in its exposure or isolation.

Sea-level rise projections: We match NIWA's extreme sea-level rise extents with relative sea-level change projections for the different climate scenarios used by the NZ SeaRise programme. These scenarios, known as Shared Socioeconomic Pathways (SSPs), represent different possible futures based on socioeconomic factors and greenhouse gas emissions. The climate scenarios considered include:

- SSP1-1.9: Very low emissions scenario, assuming rapid and significant reductions in emissions.
- SSP1-2.6: Low emissions scenario, with strong mitigation efforts.
- SSP2-4.5: Intermediate emissions scenario, often considered "middle of the road".
- SSP3-7.0: High emissions scenario, with limited mitigation efforts.
- SSP5-8.5: Very high emissions scenario.

The numbers after each SSP (e.g., 1.9, 2.6) represent the estimated radiative forcing (in W/m^2) by 2100. Higher numbers indicate greater warming potential. Projections including and not including Vertical Land Movement (VLM) are available. VLM accounts for local geological processes that can cause land to rise or sink, affecting relative sea-level rise. This report includes VLM in the projections. Projections with low confidence extend to the year 2300, while those with medium confidence extend to 2150.

Possible limitations:

- The approach does not account for geological differences between sites, such as variations in rock or sand composition, which may influence the local impacts of sea-level rise. However, these sites are approximately 2km apart along the coastline and, although these changes are important for local assessment and planning, we do not expect this assumption to substantially affect the timing of impacts.
- The NZ SeaRise data considers long-term vertical land movement and does not account for short-term responses to earthquakes. For example, the Christchurch area is expected to take another 30 years before it settles back into the long-term trend. More rapid vertical land movement is expected prior to that, meaning the speed of impacts of sea level rise are underestimated in these areas.

Reporting results: Results are reported both in terms of the centimetres of sea-level rise and the decade in which impacts are projected to occur under each climate scenario. While the approach has limitations, it provides an indication of how coastal flooding exposure and isolation risks may evolve over time, supporting adaptation planning and decision-making.

5.2 Data

5.2.1 Natural Hazards

Exposure and isolation is assessed to extreme sea-level rise and landslides:

Extreme sea-level rise extent: We use the extreme sea-level rise scenario maps developed by the National Institute of Water and Atmospheric Research (NIWA) [24]. The 1% annual exceedance probability inundation extents demonstrate how mean extreme sea-level (coastal flooding caused by storm events with large tides, waves, and storm surge) will change with sea-level rise increments ranging from 0 to 2 metres in 10cm increments. This is determined using a 'bathtub' approach and verified against sea-level run-up observations following large storm-tide events. Note that although a 1% AEP event is known as 1-in-100-year event, an event of this size has a > 63% chance of occurring at least once within a 100-year period and a 26% chance of occurring at least once within 30 years.

This analysis provides important insight into the potential risks of sea level rise and coastal flooding on infrastructure and property. The methodology employed offers a robust first-pass assessment, laying a foundation for understanding the risk. To enhance future assessments and provide context for the current findings, consider the following points:

- The analysis relies on a bathtub modeling approach, which is a simplified method for estimating the extent and depth of coastal flooding. It assumes a static water surface and does not account for dynamic factors such as waves, currents, or changes in the coastline over time. The model's accuracy depends on the quality of the digital elevation data used, which may not capture all hydrologic/hydraulic features or existing protection measures (including stormwater infrastructure, ditches, canals, etc.). More detailed local/regional studies using hydraulic models would further refine these results.
- The nationwide model used here effectively captures trends at the territorial authority level. In some areas, regional and territorial authorities may have more detailed hydraulic modeling available, which could be integrated in future analyses to provide additional granularity where needed.
- This study focuses on 1% annual exceedance probability events, important for understanding extreme weather risks and insurance implications. Future research could expand on this by examining more frequent events, such as nuisance and tidal flooding, to support planning for regular isolation and exposure scenarios.
- The current analysis considers assets as affected when flooding is >0cm, providing a conservative estimate of impact. Future studies could incorporate the depth of the hazard, enabling them to consider thresholds and vulnerability assessments to further refine our understanding of specific asset impacts.
- While this study provides a baseline, ongoing analysis will help to account for dynamic coastal processes such as erosion and subsidence, as well as the implementation of future protection measures.

These considerations underscore the importance of ongoing research and accessibility of hazard and climate models. The results presented here provide a starting point for informed decision-making and future, more detailed assessments.

Source: https://niwa.co.nz/natural-hazards/our-services/extreme-coastal-flood-maps-for-aotearoa-new-zealand.

License: The data is licensed under Creative Commons Attribution-No derivatives 4.0 International License (CC BY-ND 4.0).

Landslides: We use the 2012 nationally Highly Erodible Land dataset that was developed by Maanaki Whenua and is available from StatsNZ. This dataset includes high landslide risk zones, which will be used in this analysis. The data does not include any environmental change or temporal increments so, unlike the extreme sea level data, cannot be used to forecast how risk will change in the future as a result of how this hazard changes. A 2023 funded MBIE endeavour project ("Hazard, risk and impact modelling for fast moving landslides") aims to create, for the first-time, national scale models that characterise and quantify the risk from earthquake- and rainfall-induced landslides which could be used to update the national isolation metrics when appropriate.

Source: https://www.stats.govt.nz/indicators/highly-erodible-land.

License: The data is licensed under Creative Commons Attribution 4.0 International License.

5.2.2 Demographics, Elements, and Destinations

The following data is used in the analysis:

Population: We use census data at the Statistical Area 1 (SA1) level to provide population data. The 2018 Census data will be used as the 2023 census results were not available in time for this analysis.

Demographic information: Information about the population characteristics available at the SA1 level includes NZ Deprivation, household income, and ethnicity. The results are reported at the population level as well as by categories of these characteristics: NZ Deprivation (Deciles 1-2, 3-4, 5-6, 7-8, 9-10), household income ($0-40,000; $40,000-90,000; $90,000+), and ethnicity. The household income and ethnicity data are available from the census data, while the NZ Deprivation Index is available from Atkinson (2018) [25].

Road network: For the exposure analysis, road centrelines are available nationally from LINZ.

For the isolation assessment, the road network is available nationally from OpenStreetMap. This dataset is extracted and updated daily by Geofabrik, licensed under the Open Data Commons Open Database License.

Properties: For the purpose of this analysis, we use LINZ title boundaries and LINZ address points to define properties. This data does not include information about the parcel's use. This means that information on whether a property is residential, commercial, etc., is unavailable from a national source.

Building outlines: Building outlines are available nationally from LINZ. These are used to assess whether a building is exposed and then grouped by property title. Exposure is reported at the property-level rather than the individual building level. Using the building outline instead of the parcel itself means that properties where the buildings themselves are not exposed will not be counted.

Marae: Marae locations are available from Te Puni Kōkiri. Exposure is determined if this location is exposed to the hazard. For the purpose of the isolation assessment, Marae are treated as an origin; That is, we determine whether a marae is accessible from key activity areas and services. A marae's access to these services is considered to determine whether the marae is isolated and whether residential properties can access the marae.

Table 1 shows the list of data and their proposed sources for the analysis. This includes the list of infrastructure types included for the exposure analysis.

Table 1: Data and sources used for the analysis.

Data	Provider	Source	Date last updated
Roads	LINZ	https://data.linz.govt.nz/layer/50329-nz-road-centrelines-topo-150k/	19/12/2023
Road network	Geofabrik	https://download.geofabrik.de/australia-oceania/new-zealand-latest.osm.pbf	28/02/2024
Property Titles	LINZ	https://data.linz.govt.nz/layer/50804-nz-property-titles/	13/01/2024
Building Outlines	LINZ	https://data.linz.govt.nz/layer/101290-nz-building-outlines/	12/09/2023
Marae	TPK	https://hub.arcgis.com/maps/TPK::map-marae/about	15/06/2023
Hospitals	Ministry of Health	https://data.linz.govt.nz/layer/105588-nz-facilities/	23/06/2023
Primary Schools	Ministry of Education	https://data.linz.govt.nz/layer/105588-nz-facilities/	23/06/2023
Fire stations	FENZ	https://hub.arcgis.com/datasets/e5b44b6d9d92468aab479eed79aa353b	29/06/2022
Bridge centreline	LINZ	https://data.linz.govt.nz/layer/50244-nz-bridge-centrelines-topo-150k/	19/12/2023
Airports	LINZ	https://data.linz.govt.nz/layer/50237-nz-airport-polygons-topo-150k/	19/12/2023
Transmission Structures	Transpower	https://data-transpower.opendata.arcgis.com/	22/11/2023
Rail	LINZ	https://data.linz.govt.nz/layer/50319-nz-railway-centrelines-topo-150k/	19/12/2023

To our knowledge, suitable data for landfills, three waters, and telecommunications is not currently available nationally.

6 Future analysis

This report provides insights into the potential impacts of coastal flooding and landslides on New Zealand's infrastructure and communities. However, assessing climate change risk is a dynamic and rapidly evolving field. New hazard models are continually being developed, risks are changing due to climate change, and both asset locations and demographics are in flux. This underscores the need for ongoing research and regular reassessment.

6.1 Dynamic Nature of Risk Assessment

- Evolving Hazard Models: As our understanding of climate change impacts improves, new and more sophisticated hazard models are being developed. Future analyses should incorporate these advancements to refine risk assessments. For instance, there are several ongoing and recently completed Endeavour Research Programmes and National Science Challenge projects working on river flooding, coastal flooding, wildfire, and landslide hazards (among others).

- Climate projections: Climate change projections are also improving. Regular updates to risk assessments are required to capture these evolving future pathways.
- Demographic and Asset Changes: Population movements, urban development, and infrastructure changes can significantly alter risk profiles. Our current analysis relies on the 2018 census data, as 2023 data was unavailable at the time of the study. Future assessments should incorporate the most recent demographic and asset information.
- Need for Dynamic Assessments: To ensure the most up-to-date and reliable evidence is being used for risk management, it is critical that these types of assessments become 'living' platforms or the documents are updated regularly and consistently. This allows for monitoring of risk trajectories, enabling quick action if risks approach intolerable levels.

6.2 Methodological Enhancements

- Aggregation of Local Assessments: Future work would benefit from aggregating locally-specific district and regional assessments into a national picture, rather than relying solely on nation-wide datasets. This approach could provide more nuanced, locally-relevant insights while maintaining a comprehensive national overview. This requires consistent approaches to risk assessment around the country. Aggregating local assessments would likely improve the feasibility of using hydrodynamic (instead of bathtub) flood models and incorporating protective structures.
- Expanded Hazard Analysis: Incorporating a wider range of hazard types, return periods and any data updates would offer a more comprehensive understanding of risk. Incorporating a range of return periods would help capture the impacts of more frequent, lower-intensity events that can have significant cumulative effects on communities and infrastructure.
- Vulnerability Assessment: Developing a consistent library of vulnerability curves for different infrastructure types and hazards would enhance the accuracy of impact assessments. This would allow for a more nuanced understanding of how different assets respond to various hazard intensities.

6.3 Data and Scope Expansion

- Infrastructure Coverage: Expanding the analysis to include a more comprehensive range of infrastructure types, such as local electricity distribution networks, landfills, water supply networks, and telecommunications, would provide a fuller picture of potential impacts. This could be achieved through improved nationally available data sources or by aggregating consistent local risk assessments.
- Cascading Impacts: Consideration of cascading failures, such as power outages resulting from infrastructure damage, would provide a more comprehensive understanding of potential economic and social impacts.
- Dynamic Population Projections: Incorporating projections of population dynamics in coastal areas could offer valuable insights for long-term planning, acknowledging potential shifts in exposure due to migration or retreat.
- Adaptive Measures: Future research could explore the potential impacts of various adaptation strategies, such as sea walls, managed retreat, or nature-based solutions, to assess their long-term effectiveness.

6.4 Limitations and Considerations

It is important to acknowledge certain limitations of the current study:

- Protective Structures: Our analysis does not account for existing protective measures, which may lead to an overestimation of inundation in some areas. However, excluding these structures also highlights the importance of their maintenance and the potential consequences of their failure.
- Asset-Specific Details: Due to data limitations, some asset-specific details (such as bridge deck heights) were not incorporated. While our approach remains robust for broad-scale analysis, more detailed data could refine local-level assessments.
- Event Frequency: Our focus on 1% annual exceedance probability events provides insights into extreme weather risks but may not fully capture the impacts of more frequent, lower-intensity events. Additionally, this 1% return period does not account for potential changes in the frequency of these events beyond changing sea level. Climate change may alter storm patterns and intensities, potentially making what is currently a 1% event more frequent in the future. The event frequency also matters when comparing isolation and exposure, as individuals are likely more tolerant to the risk of isolation than they are to direct exposure. Isolation risk assessed based on MHWS models, for instance, would provide information on where much more regular isolation would burden residents.
- Temporal Snapshot: This analysis provides a snapshot based on current data and models. Given the dynamic nature of climate risks and societal changes (including land use), regular updates will be necessary to maintain the relevance and accuracy of the findings.
- Data Currency: The use of 2018 census data, while the most recent available for this study, may not fully reflect current demographic patterns. Future studies should prioritise using the most up-to-date data available.

These limitations and future research directions do not undermine the credibility or importance of our current findings. Rather, they underscore the complexity of climate change impacts and the need for ongoing research and refinement of our understanding. The present analysis provides a robust foundation for ongoing monitoring while highlighting avenues for future research to enhance our preparedness for coastal flooding and landslide impacts.

By addressing these areas in future studies and maintaining a commitment to regular reassessment, we can continue to build upon the valuable insights provided in this report. This ongoing process will enable developing and adapting effective, equitable, and resilient strategies for New Zealand's communities and infrastructure in the face of changing climate risks.

The dynamic nature of this field emphasizes the importance of viewing this report as part of an ongoing process of risk assessment and adaptation planning, rather than a final statement. Regular updates and reassessments will be essential to ensure that decision-makers have the most current and accurate information to guide their strategies for climate resilience.

7 Data Generated

An xlsx file of results at the Territorial level has been provided along with the report, this includes the following tabs:

- `Exposure_Infrastructure`
  This tab has the infrastructure exposure results.
- `Exposure_Population`
  This tab uses the property exposure and census data to estimate the number and demographics of the residents exposed.
- `Isolation_Infrastructure`
  This tab presents the estimates for property and marae isolation from schools, hospitals, and fire stations.
- `Isolation_Population`
  As before, this tab estimates the number of residents based on census demographic groups, that may be isolated from schools, hospitals, and fire stations.

The columns of the sheets are:

Column Name	**Description**
hazard_type	Hazard type
territorial_authority	Territorial Authority
element_type	Infrastructure/asset type
demographic	For the *Population* tabs: the census variable in question
slr	The sea-level rise associated with the hazard (for landslides this is N/A)
aep	The annual exceedance probability of the hazard (for landslides this is N/A)
unit	The unit of *value* and *total*
value	The exposed amount of the infrastructure type in the unit specified
total	The total amount of the infrastructure type in the territorial boundary
percentage	The percentage of the infrastructure that is exposed.

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