RiskScape™ Case Studies: Informing Land-Use Planning Through Natural Hazard and Climate-Change Risk Modelling

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ABSTRACT

Aotearoa New Zealand faces substantial challenges to respond to natural hazard risk and climate change. This is compounded by the need to provide residential zoned land for urban housing needs, commercial and industrial land for economic development and also maintain rural land for primary production. Scalable processes and frameworks are needed to support effective and efficient decision-making that is both robust and replicable. Therefore, tools that can be used to face these challenges and avoid maladaptation are needed. This report demonstrates ways in which RiskScape™, an open-source spatial data processing application used for multi-hazard risk analysis, can be used to produce evidence-based risk assessments incorporating different land-use planning directions, hazard mitigation and adaption strategies and risk acceptance/tolerance thresholds.

Four challenges encountered by planning practitioners have been explored:

- Greenfield development with multiple hazards.
- Policy interventions (protect, avoid, reduce and accept) within an urban flood plain.
- Climate-change interventions and scenarios, land-use intensification settings and adaptation options in a coastal setting.
- A component of a Dynamic Adaptive Policy Pathway (DAPP) approach for a coastal settlement.

The focus of this study was on the Auckland region and included four case studies to highlight the capability of RiskScape™. While content for these cases has been developed in collaboration with Auckland Council to provide applied and relevant examples, the outputs do not represent or consist of direction or recommendation for Auckland Council to implement, nor do they represent possible changes to policy settings, such as level of tolerable risk being considered by Auckland Council.

These cases were selected as they are replicable and relevant across Aotearoa New Zealand and demonstrate the ways in which RiskScape™ can be used to support consultation, cost-benefit analysis, adaption options and, ultimately, decision-making.

The results from these cases include:

- Identification of hazards (none/one/multiple) in a future development area to inform further spatial planning.
- Flooding in an urban area with an output of a range of options showing how different adaptation options could reduce the risk by targeting specific high-risk areas, while still allowing for some development potential to be retained.
- In the coastal context, understanding that the impact on risk from climate change and intensification – the impact of retreat / no further intensification – could reduce the overall risk in an area to an acceptable level. Also, understanding with increased certainty when some residential dwellings can expect ongoing disruption to access due to coastal inundation, as well as the suitability of triggers in a DAPP process.

KEYWORDS

Risk assessment, natural hazard adaptation and mitigation, RiskScape, Dynamic Adaptive Policy Pathway (DAPP)

1.0 INTRODUCTION

1.1 Purpose and Focus

This report demonstrates ways in which RiskScape™ can be used to produce evidence-based risk assessments comprising land-use planning directions, hazard mitigation and adaptation strategies incorporating climate change and risk acceptance/tolerance thresholds. RiskScape™ is a software application that allows multi-hazard datasets and land-use planning options to be modelled to understand the resultant risk profile and provide evidence for a cost-benefit analysis by comparing different policy options.

This report utilises case studies from the Auckland region; however, outputs from these cases does not represent direction or recommendations for implementation. These case studies were selected as they are replicable and relevant across Aotearoa New Zealand and demonstrate the ways in which RiskScape™ can be used to support land-use planning processes, including through consultation, cost-benefit analysis, adaptation options and, ultimately, decision-making. Scientifically grounded outputs from a comprehensive and repeatable process provide robustness and certainty that a variety of options have or can be interrogated.

The cases studies explored include:

- Greenfield development with multiple hazards.
- Policy interventions (protect, avoid, reduce and accept [PARA]) within an urban flood risk area.
- Climate-change interventions and scenarios, as well as land-use intensification settings and adaptation options, in a coastal setting.
- A component of a Dynamic Adaptive Policy Pathway (DAPP) approach for a coastal settlement.

1.2 Land-Use Planning and Modelling for Natural Hazards in Aotearoa New Zealand

Aotearoa New Zealand is a group of geologically diverse islands, perched across an active plate boundary, with some 15,000 km of coastline and many river systems. While this creates a physically stunning environment, it also presents a natural hazard risk when land is developed and used. This risk is compounded by the effects of climate change both now and in the future.

The legislative framework for managing natural hazards in Aotearoa New Zealand comprises several pieces of legislation and their respective instruments. These are canvased in previous publications such as Glavovic et al. (2010), Saunders et al. (2013), Saunders and Kilvington (2016), Saunders et al. (2007) and Saunders and Beban (2012). With the addition of resource management reform legislation, this is summarised in Appendix 1.

To support decision-making under these frameworks, there is a need for tools with which to develop an evidence base to enable risk-based decision-making. These tools need to be able to incorporate natural hazard data, such as depth of flood from a 1% annual exceedance probability (AEP) event; set risk tolerance levels (e.g. accepting the risk from 20 cm of inundation in residential dwellings during a 1% AEP event); and input land-use planning parameters, such as permitted building coverage. Tools also need to be flexible, including being able to adjust parameters to understand the resultant impact on risk of changing land-use planning parameters, such as decreasing the permitted building coverage. RiskScape™ is such a tool. Providing an evidence basis for options analysis, with cost-benefit analysis,is critical to community understanding of natural hazard and risk and, ultimately, to decision-making.

An overview of natural hazard risk models, development and case studies is contained in Appendix 2. Detail on the RiskScape™ modelling framework and technical detail on pipeline development are provided in Appendix 3. RiskScape™ pipelines and input data (where already publicly available) used in the four case studies are available at https://github.com/GNS-Science/riskscape/tree/main/projects/land-use-planning-case-studies

2.0 METHODOLOGY

This study involves demonstrating, through a series of case studies, how RiskScape™ can be used as an assessment tool to assess, evaluate and, ultimately, manage the natural hazard risk through land-use planning. The cases are intended to showcase the capability of RiskScape™ for land-use planning applications and for the case studies to be replicable in other locations.

The selection of areas for the four case studies was informed by a literature review, engagement plan and series of workshops with Toka Tū Ake EQC, Auckland Council and GNS Science. Following this, the selection of case studies modelling was undertaken. The results were shared by GNS Science at two further workshops with Toka Tū Ake EQC and Auckland Council. The pipeline code developed through this project is openly available through GitHub – see Section 6.

The purpose and process of those steps are detailed further below:

- **Literature review:** A literature review was undertaken to understand the way in which RiskScape™ has been used to inform land-use policy setting and decision-making, as well as other tools that support risk-based decision-making. The literature review is not a comprehensive study of all risk modelling tools used for land-use policy setting and decision-making. It is targeted on the published RiskScape™ case studies and how they were developed, as well as a comparison with other risk assessment tools. The purpose of the review is to inform the engagement plan and case-study selection for this study. The review is contained in Appendix 4.
- **Engagement plan:** An engagement plan was formulated to guide collective preparation for the case-study selection workshops, which set the modelling parameters within the policy context and physical environment. The engagement plan included consideration of the different levels of input that parties had to the project and ways in which risk could be managed through the process, and aligned the case studies with current work programmes to ensure that they were grounded in real situations that are likely challenges also faced by other councils. Auckland Council is the largest council within Aotearoa New Zealand, with many plans and strategies being worked on concurrently. To work as efficiently as possible, a lead person was identified for three key directorates: Plans and Places (Regulatory Planning), Shoreline Adaptation (Asset Management and Engineering) and the Chief Sustainability Office (Climate Change).
- **Case-study selection workshops:** A series of workshops were held with attendees from Toka Tū Ake EQC, Auckland Council and GNS Science. The workshops firstly set out the four scenarios to be modelled and the purpose of the study. For each scenario, the following matters were addressed: specific criteria that will optimise the use of RiskScape™, location and scale, planning and policy options (including spatial identification and description), datasets required, engagement required outside of the workshop group and any risks/issues. Several workshops were necessary to ensure that all parties had the best possible opportunity to consider the criteria. Data availability guided the final case study selection. The group were cognisant that it was insensitive to include areas with a high level of community anxiety following the recent natural hazard events (Anniversary flooding and Cyclone Gabrielle). The capacity of teams within Auckland Council to provide input was also a consideration. A further consideration was seeking to include a spectrum of physical environments and their associated natural hazards.

- **Modelling:** The modelling methodology for pipeline development is detailed under each case study in Section 3.
- **Results Workshops:** The modelling outputs were shared via two workshops with Toka Tū Ake EQC and Auckland Council. The results and interpretation are in Section 3. The pipelines and input data (where already publicly available) used in the four case studies are available via GitHub. Workshopping the modelling outputs tests the future usability for decision-making. It also ensures that, if the outputs are used to inform changes to land-use policy, there is confidence that a comprehensive repeatable process has been undertaken. By making the outputs publicly available, other users will be able to replicate or be guided by the project.

3.0 USING RISKSCAPE™ FOR RISK-BASED LAND-USE PLANNING

3.1 Overview

Four case studies were identified in collaboration with Toka Tū Ake EQC and Auckland Council to demonstrate ways in which RiskScape™ can be used to inform land-use planning. The case studies are outlined below, and locations are shown in Figure 3.1. The RiskScape™ pipeline is set out in bullet points for each case study under Section 3.2.2. These are the key points that potential users can follow to replicate the process.

1. **Greenfield (Drury):** RiskScape™ was utilised to undertake an initial assessment of a rural area (greenfield) to identify areas within it that have no, one or multiple hazards. This RiskScape™ pipeline could be used to undertake the type of assessment required as part of the development of a Regional Spatial Strategy. This type of analysis is also applicable to modelling brownfield development or intensification.
2. **PARA option analysis (Te Auaunga / Oakley Creek):** This case study demonstrates how a PARA type of intervention-option analysis could be undertaken using RiskScape™ in an urban flood plain. A RiskScape™ pipeline was created to model the baseline future risk with no change to the current policy approach. The model was then reconfigured with policy intervention options to understand the change in future risk. The difference in future risk between the baseline (do nothing) and intervention options can be used to show the potential risk reduction from implementing policies and can be input into a cost-benefit analysis.
3. **Climate change intervention (Orewa):** RiskScape™ was utilised to explore policy interventions against a baseline and a change of hazard over time due to climate change. The hazard that is modelled for Orewa is coastal inundation, with the sea-level increases linked to different climate-change scenarios.
4. **DAPP processes (Maraetai):** Maraetai Drive has been used to demonstrate the application of a DAPP in a coastal context, focusing on consequences for transport infrastructure when subject to coastal inundation. A range of timeframes and hazard scenarios are used to develop potential pathways. This case study represents a first step of a DAPP process, and is not intended to be a full process, but does show the ways that RiskScape™ can be used in an iterative manner to support development of DAPP projects. This case study could also be implemented as part of shoreline adaptation and/or as part of transport asset management strategy.

Figure 3.1 Map showing locations of the four case studies in Auckland. Greenfields – Drury; PARA – Te Auaunga / Oakley Creek; Climate Change Intervention – Ōrewa; DAPP – Maraetai.

3.2 Greenfield Case Study

3.2.1 Location and Policy Context

Drury is a South Auckland suburb and has been subject to extensive development through the Auckland Unitary Plan (AUP)[1]. Further, Drury South and Drury West (Bremner Road) are subject to a plan change process to enable residential and commercial development. These areas are currently zoned as Rural or Future Urban. The Future Urban Zone is a transitional zone. Land may be used for rural purposes until re-zoning occurs, and the provisions are similar to the Rural – Productive Land provisions. Drury West Stage 1, Drury West Stage 2 and Ōpaheke would potentially provide a further 17,800 dwellings through the Future Urban Land Supply Strategy (Auckland Council 2017). The strategy seeks to give effect to the National Policy Statement – Urban Development (NPS-UD) by providing greenfield development areas. Some of these areas are not scheduled to be re-zoned to Residential until 2028–2032.

1 AUP zoning can be viewed at https://unitaryplanmaps.aucklandcouncil.govt.nz/upviewer/.

Resource management reform, and particularly the Spatial Planning Act 2023[2], will be implemented in tranches. It is not yet clear which tranche Auckland will be in. However, it is likely that development areas such as these will need to be considered as part of a future Regional Spatial Strategy if development is envisaged within the next 30 years.

The National Policy Statement for Highly Productive Land (NPS-HPL; Minister for the Environment 2022) seeks to protect highly productive land for primary production and avoid other uses. Specifically relevant to this report is Policy 5, which would restrict the potential yield from re-zoning the area:

> *"The urban rezoning of highly productive land is avoided, except as provided in this National Policy Statement".*

The Pukekohe area is well known for its highly productive soils (Bland et al. 2023). The soil classifications and potential development area have been reviewed and do not include 'highly productive soils', while noting that the definition used in the AUP is a transitional definition and may change. A definition of highly productive land is included in the NPS-HPL.

3.2.2 Identified Hazards and RiskScape™ Model Framework

The case-study area has been identified as subject to five natural hazards. For hazard analysis, six datasets were available (see Figure 3.2) with coverage at national, regional and local levels:

- **Tsunami evacuation zones:** This hazard layer was informed by the 1:2500-year 84th percentile confidence interval. This type of hazard layer is typically developed for Civil Defence Management groups and is available for most regions in Aotearoa New Zealand. In this instance, the data is owned by Auckland Council. The detail/level of analysis required for land-use planning provisions to address risk from tsunami is set out in the Tsunami Planning Guidelines (Beban et al. 2019), and layers developed for Civil Defence purposes are not typically sufficient for land-use planning provisions. However, as the objective of this case study is to identify areas 'at risk' from hazards as a screening exercise, use of these layers is considered appropriate in the absence of more detailed information.
- **Active Fault zones:** Red lines are mapped fault traces, and red polygons are the fault avoidance buffer zones based on the Ministry of the Environment Active Fault Guidelines (Kerr et al. 2003). This case study uses recently compiled data from Bland et al. (2023). Mapped fault traces are available at various spatial scales across Aotearoa New Zealand through the Active Faults Database. The Bland et al. (2023) data has not yet been added to the Active Faults Database.
- **Liquefaction susceptibility:** This layer shows the potential of liquefaction ranging from very high (dark red zones) to negligible (green zones). It is available for all of Aotearoa New Zealand and is developed by GNS Science. The New Zealand Building Code was amended in 2021, which now recommends mapping of vulnerability levels. Development of a national model is ongoing.

2 At the time of publication, there was uncertainty as to the future of the Spatial Planning Act and other aspects of the resource management reforms. Notwithstanding this uncertainty, the approach presented in this report can be applicable for any resource management system.

- **1% AEP regional flood model:** This hazard layer is a regional 1% AEP flood layer owned by Auckland Council. This is used for regional-scale flood analysis and is typical of regional flood maps held by councils in flood-prone regions. The hazard is represented by estimated maximum flood depth.
- **Landslides susceptibility:** This layer shows the potential of landslides ranging from very high (dark red zones) to negligible (green zones). It is available for all of Aotearoa New Zealand and is developed by GNS Science. Other councils may have more detailed landslide susceptibility mapping for their districts/region that may be more appropriate.
- **Landslide units:** These are existing landslides that have been mapped and would require further investigation if development were to occur on them. They have been mapped by GNS Science. This type of hazard layer is available across Aotearoa New Zealand in regional-scale geological maps and at higher spatial resolution in some regions in Aotearoa New Zealand.

As can be seen from the list of available data above, the hazard data is inconsistent in both likelihood and hazard definition. Some are defined as AEP (e.g. 1% AEP flood, 0.02% AEP tsunami), some as recurrence intervals and complexity classifications (e.g. active fault data) and others have no likelihood information (e.g. the susceptibility layers). Some layers have hazard-intensity values (e.g. flood depth), while others are categorical data such as susceptibility or binary outcomes (e.g. in or out of a tsunami zone). This is typical of data that is commonly available ‘off the shelf’ for risk screening analysis across Aotearoa New Zealand. For the purposes of the analysis being undertaken here, reconciling the differences across the datasets is not necessary. Instead, these datasets are utilised as a first step of analysis to determine where further investigation may be required or to identify preferred development areas.

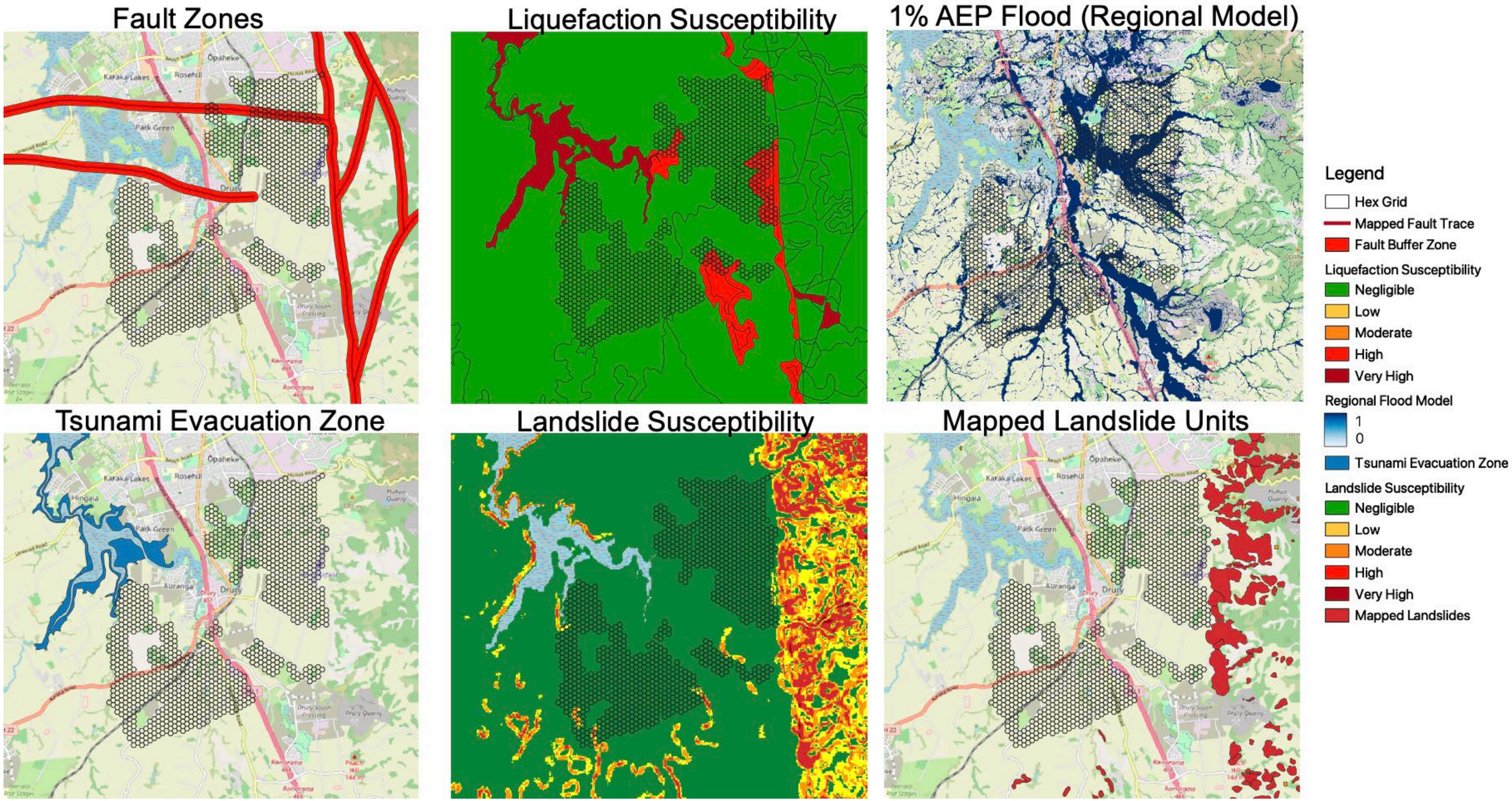

Figure 3.2 Example of RiskScape™ hazard-exposure analysis showing intersection of exposure grid with six available hazard datasets for hazards with the potential to impact the greenfield case-study area (Drury).

At the commencement of a greenfield land-use planning cycle, natural hazard risks should be identified in a time- and cost-effective manner. The proposed approach for RiskScape™ in this context is to undertake a hazard-exposure analysis, where the analysis determines whether a given hazard has the potential to impact a location (e.g. Figure 3.2). This could also be considered a 'risk screening' exercise. It is assumed that, following this initial analysis, further hazard and risk modelling studies would be undertaken to further investigate the potential impacts if an area is deemed suitable for development.

The following process was followed to develop the RiskScape™ pipeline:

- **Define the greenfield area for future development.** Two areas, zoned as future urban zones in Figure 3.3 (grey polygons), have been used in this case study.

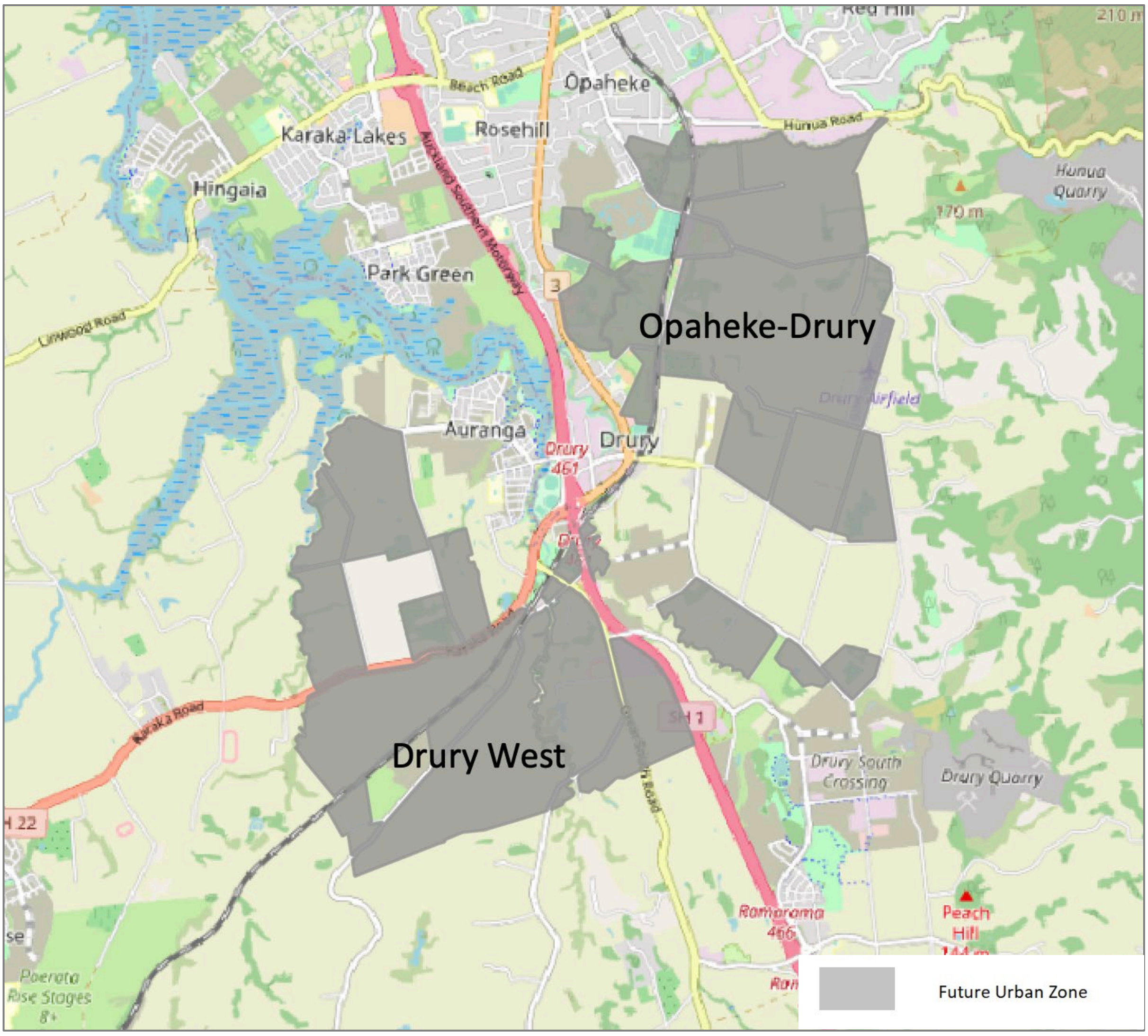

Figure 3.3 Polygons representing future urban zones in Drury.

- To **identify where buildings would be in a future development area**, the large polygons can be divided into smaller areas (grids) to check the potential risk in those smaller parcels. Within RiskScape™, the geometry of the grid can be chosen (e.g. square grid, hexagon grid), as well as the size of grid, which, in this case, is a 100 m x 100 m hexagon grid (Figure 3.4). This was selected as giving the most complete cover of the area in this instance.

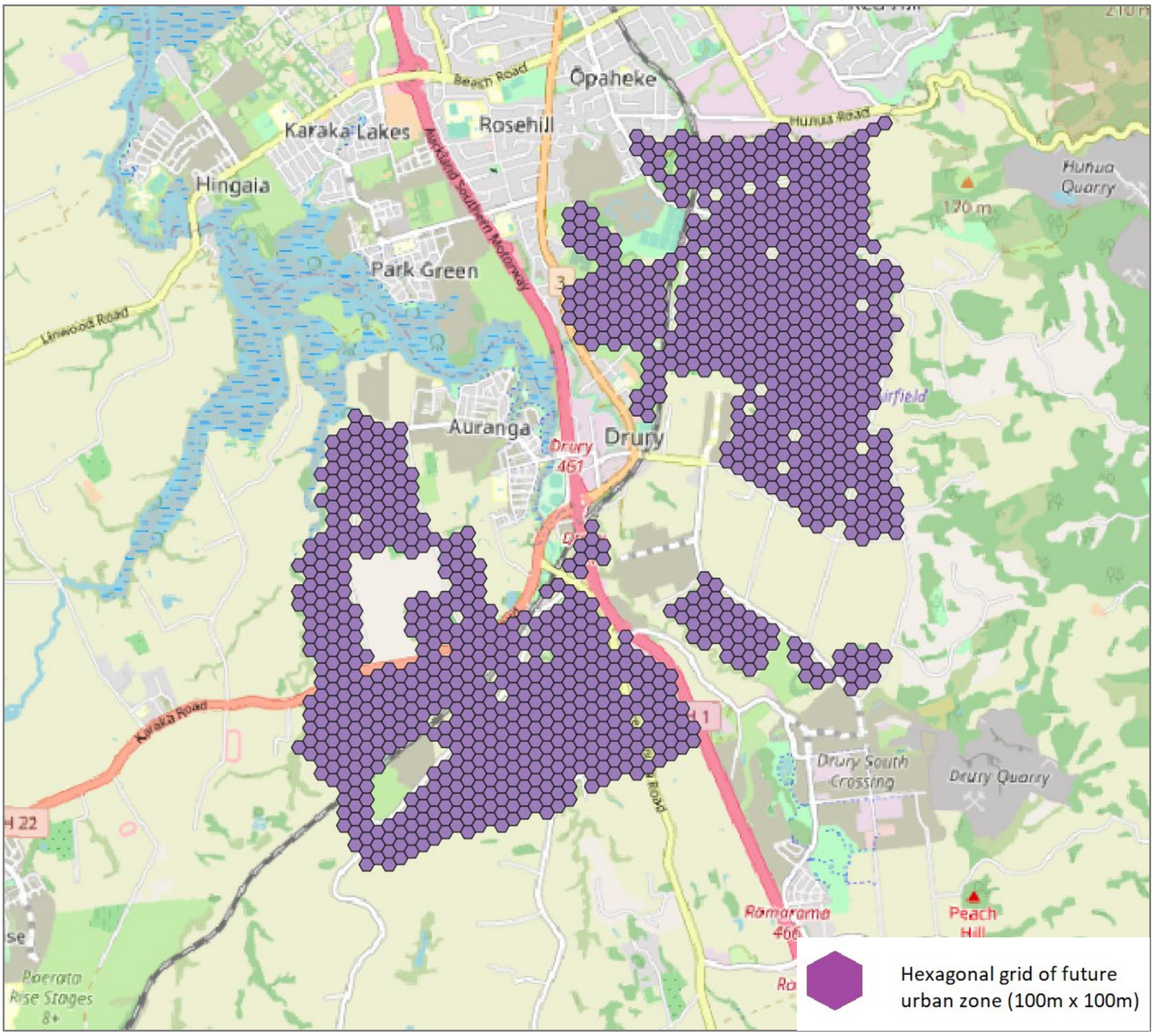

Figure 3.4 100 m x 100 m hexagon in future urban zones in Drury.

- **Define the natural hazard data available, then undertake a natural hazard intersection** with the different hexagons to get a value of the hazard (singular) within that hexagon. Figure 3.5 shows the output for liquefaction damage.

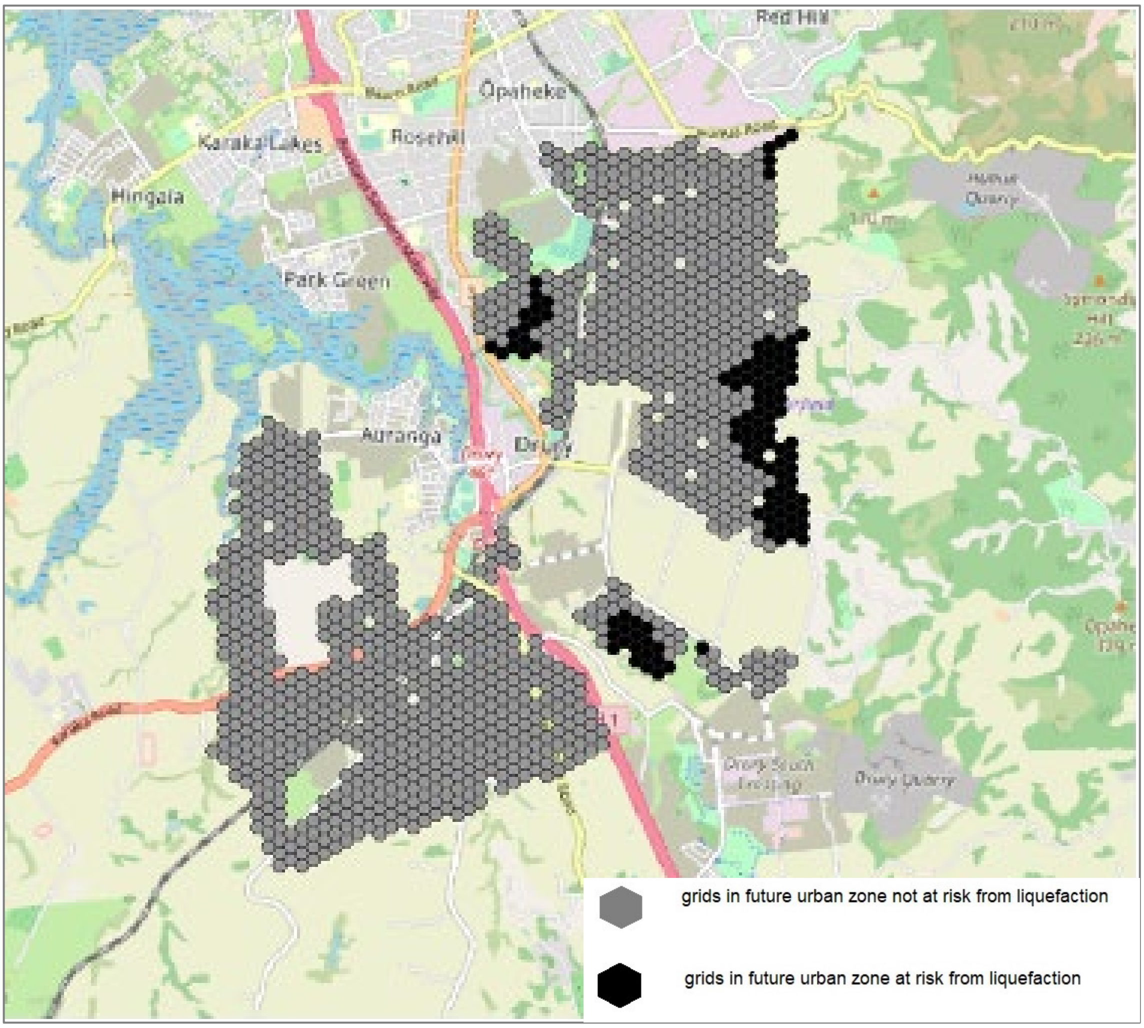

Figure 3.5 Example of RiskScape™ result showing grids in future urban zones (all hexagons) that are at risk from liquefaction damage (black hexagons). Note that the figure shows a different extent to the area recommended by Council for removal from the Future Development Strategy.

- **Set the risk thresholds for each natural hazard.** In this instance, risk is assigned in a binary form that identifies whether that grid is ‘at risk’ or ‘not at risk’, dependent on the risk threshold being set for the hazard. In this case, if the value of a hazard is above the risk threshold (for instance, flood depth above 0.2 m, indicating the level at which damage would occur), then that hexagon is identified as being ‘at risk’. For each of the hexagons shown in Figure 3.6, a multi-hazard risk score is calculated after overlaying all of the hazards. The risk score per grid cell is calculated as:

  $$risk\ score = (exposed_1 \times\ weight_1) + (exposed_2\ \times\ weight_2) + (exposed_n\ \times\ weight_n)$$

  where *exposed*$_n$ is a value of 1 if the grid cell is ‘at risk’ (i.e. the hazard value is above the set threshold) from the hazard *n*, and a value 0 if the grid cell is ‘not at risk’ (i.e. the hazard value is below the set threshold). Note that a grid cell will be assigned as ‘at risk’ if any of that cell has a hazard value above the set threshold. If the flood depth threshold is set to 0.2 m, a hypothetically acceptable level of flooding, then, if any of the flood hazard data within a grid cell is above 0.2 m, the entire grid cell will be assigned as ‘at risk’.
- **Assign a weight to each hazard**; this allows the user to increase or decrease the influence of each hazard. In this example, the weights are all set to 1, therefore each hazard is weighted equally. This could be set to other values, for example, to give more weight to landslide than flood, to test policy directions.

Figure 3.6 displays the combined results for this case study. The grey hexagons have no hazards identified through available data, orange areas have at least one hazard affecting that area and red areas are affected by more than two hazards. No area within the two modelled FUZ zones are affected by more than two hazards. These results could be used to identify areas where more detailed natural-hazard investigations may be needed.

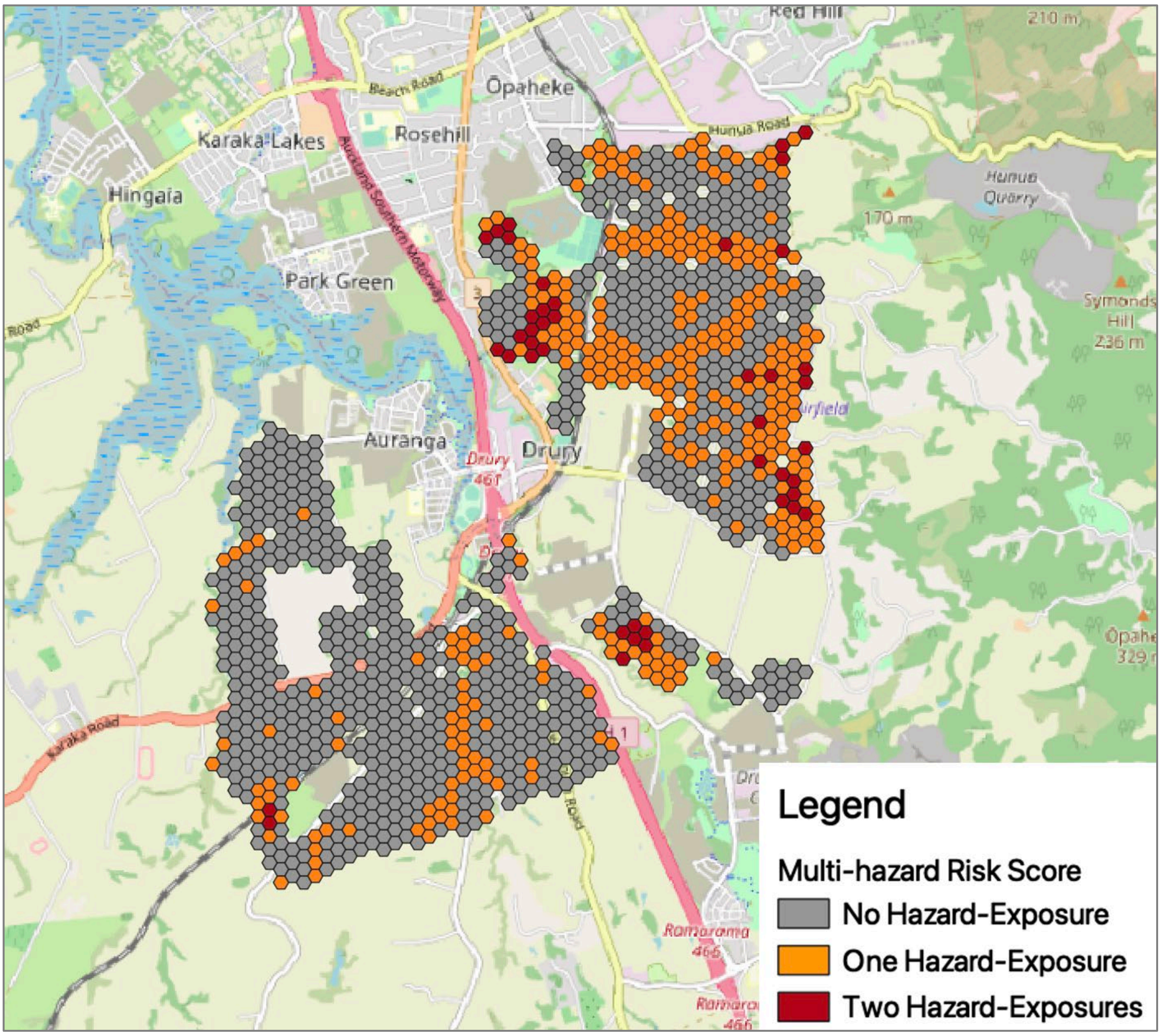

Figure 3.6 Demonstration of potential multi-hazard risk score, with grey areas indicating negligible risk, orange areas indicating those with potential impact from one hazard and red areas indicating those affected by two hazards.

3.3 PARA: Protect, Accommodate (Accept), Retreat (Reduce), Avoid

3.3.1 Location and Policy Context

Te Auaunga / Oakley Creek runs from Mt Roskill through several central West Auckland suburbs, discharging into the inner Waitemata Harbour near Point Chevalier. The area has been zoned to be intensified through the AUP. Current zones immediately next to the creek are a mixture of Residential – Terraced House and Apartment Building, Residential – Mixed Housing Urban and Residential – Mixed Housing Suburban. The area could potentially be further intensified through Proposed Plan Change 78 (PC78)[3], with a minimum of three dwellings of three storeys, notwithstanding qualifying matters. This study does not explore the total number of extra dwellings that could be achieved. Analysis of all qualifying matters is addressed in evaluation documents supporting PC78.

In response to Cyclone Gabrielle and the Auckland Anniversary flood events, Healthy Waters, the stormwater operations department of Auckland Council, developed the 'Making Space for Water' programme, which was presented to the Auckland Council Governing Body in June 2023 and comprises nine initiatives:

1. **Blue-green networks in critical flood-risk areas:** Stormwater solutions (stream daylighting, widening and re-alignment), enhancing parkland or open space, property acquisition and removal.
2. **High-risk properties:** Working with property owners on engineering solutions, managed retreat and property acquisition.
3. **Culvert and bridge upgrades:** The assessment, replacement and upgrade of vulnerable assets.
4. **Overland flow-path management:** Work to repair, maintain and monitor overland flow paths, as well as to educate property owners.
5. **Rural settlements:** Responding to three waters needs in storm-affected communities, including marae and papakāinga, and supporting community resilience planning.
6. **Flood intelligence:** Investment in planning and modelling tools to enhance council decision-making.
7. **Stream rehabilitation:** Vegetation management, slope stabilisation, bank battering, stream-channel modification, advice for property owners.
8. **Community-led flood resilience:** Advice for property owners in high-risk areas, industry-specific advice, public events, awareness campaigns.
9. **Increased maintenance:** Maximising the stormwater network's efficiency, including street sweeping, catchpit cleaning and weed clearance from streams.

This case study takes elements of those initiatives to consider four risk management approaches via land-use planning: Protect, Accept, Reduce, Avoid (PARA). In this case study, the PARA options could be implemented as follows:

- **Protect:** Hard protection structures and the cost of implementing these. This initiative is not included in the case studies, as it requires new hazard data to be modelled, which is out of scope of this project.

3 Proposed Plan Change 78 is detailed in Appendix 1.

- **Accept (Accommodate):** Raise floor heights. The current AUP requirements are 500 mm over a 1% AEP flood event.
- **Reduce:** Blue Green Networks comprising stormwater solutions (stream daylighting, widening and re-alignment), enhancing parkland or open space, property acquisition and removal.
- **Avoid:** No further development/intensification.

3.3.2 Identified Hazard and RiskScape™ Modelling

The goal of this case study is to use RiskScape™ to quantify the benefit of various PARA intervention options for future risk in a flood plain. The following process was undertaken to create a RiskScape™ pipeline:

- **Model the baseline future risk (no change to existing land-use policy), then reconfigure and remodel with policy intervention options to show the difference in future risk.** The difference in future risk can be used to show the potential risk reduction from implementing policies and contribute to cost-benefit analysis. The future risk in this case study is quantified as the re-instatement cost for future flood scenarios of different AEPs, as well as the average annual loss (AAL) which is the long-term average cost per year to repair flood damage. The AAL can be thought of as the annual repair cost if losses are annualised across all possible flood events.
- **Model a series of scenarios with differing AEPs in order to be able to understand the flood risk across a spectrum of possible flood scenarios.** To understand the flood risk, a range of scenarios with differing AEP (5, 2, 1, 0.5, 0.2, 0.1, 0.01%) are used to allow a spectrum of possible flood scenarios to be considered. This is also useful to determine a risk metric appropriate for decision-making, which is annualised loss or annualised risk that requires a range of AEPs. In Figure 3.7, a scenario of 0.01% AEP or 10,000 years AEP is shown to identify the maximum credible extent of flooding in the catchment. Auckland Council does not hold all of these scenarios, so further data was sourced from Ambiental.

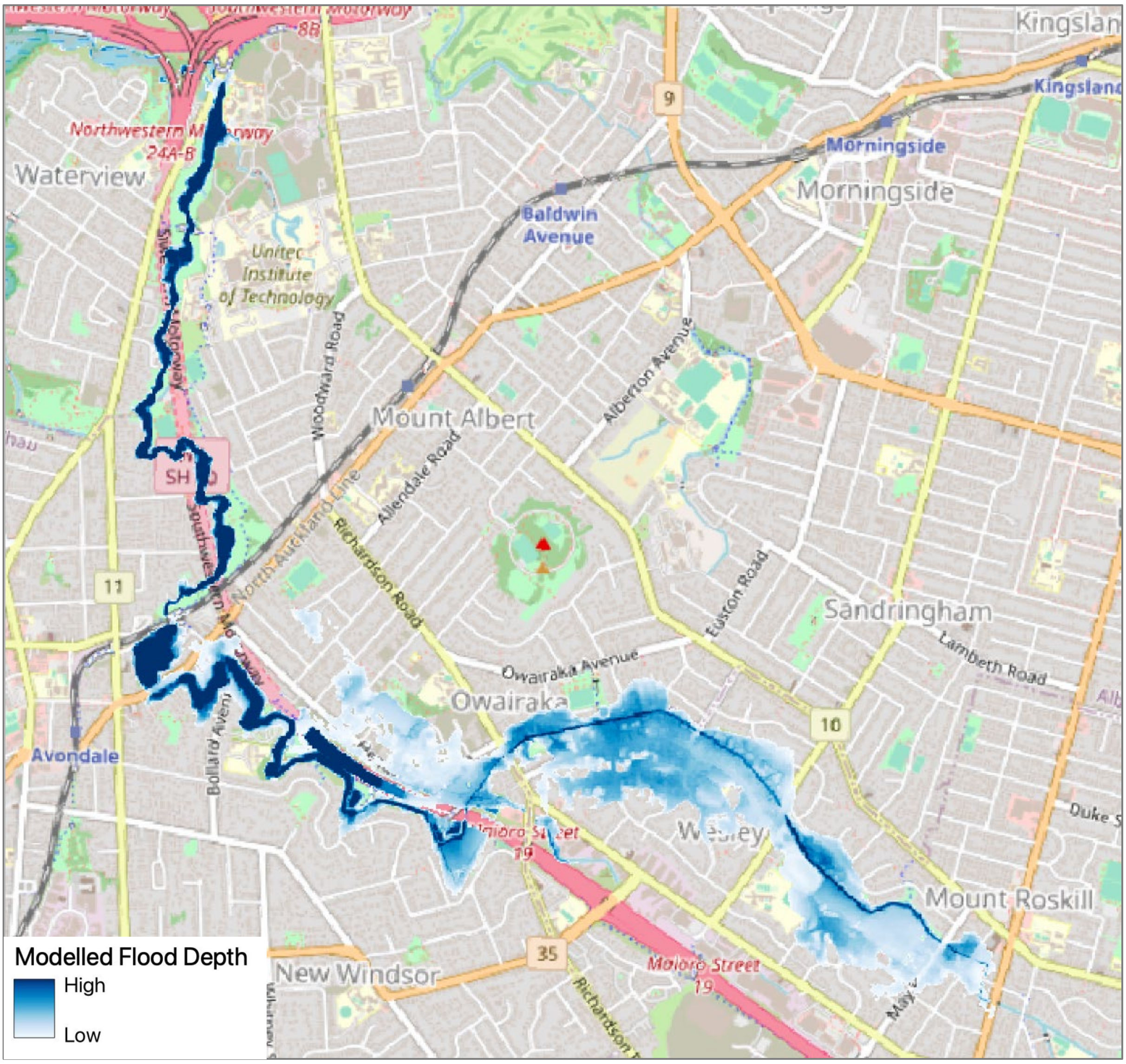

Figure 3.7 Map showing the Te Auaunga / Oakley Creek flood plain with the extent of the 0.01% AEP (1-in-10,000 per year likelihood), i.e. maximum credible flood extent flood shown. Darker blue colours represent deeper flood depths.

- **Choose a planning timeframe** – in this case study, a future risk date of 2120. To understand the future risk, exposure data need to be modified from the present to potential exposure in 97 years. Note that climate-change impacts on the hazard to 2120 have not been incorporated into this case study due to a lack of flood hazard data with future climate projections.
- **Examine future intensification levels.** The AUP zones have varying levels of residential intensification that can occur as a permitted activity that do not require a resource consent but must meet standards. For example, in the Residential – Mixed Housing Urban zone, a site might have a maximum building coverage of 60% and a maximum height of three stories. The Residential – Terraced House and Apartment Building zone does not have a permitted activity for residential dwellings. The standards for the restricted discretionary activity have been used as a proxy for permitted activity standards with three dwellings – as the zone is intended to be the most intensive, it is reasonable to assume that as least as many dwellings are anticipated in the less-intensive zones. These levels of intensification are applied to the existing property parcels in the case study area within flood catchment as the hazard to show the permitted activities per land parcel (see Figure 3.8).

Figure 3.8 Auckland Unitary Plan zones for the flood catchment area with overlying land parcels (Land Information New Zealand primary land parcels).

- **Define maximum intensification possible within the planning timeframe.** Shown on the right side of Figure 3.9 is the maximum growth if every property parcel would be developed to its maximum under the permitted activities by 2120. One thing to note here is that the maximum intensification is the extreme case and very unlikely, but RiskScape™ provides an option to choose a percentage of properties that would be intensified at the selected planning horizon. For example, a future exposure for 20% of land parcels to be intensified at their maximum could be generated. At present, the rate of intensification is linear over time; however, greater flexibility can be incorporated to model where and when intensification occurs. Repair costs are estimated for each building and then aggregated for the whole catchment.
- **Generate future exposure datasets.** Once the rate of development has been set, RiskScape™ generates future exposure datasets at each year between the current year (e.g. 2023) and the future planning horizon date (e.g. 2120).
- **Calculate risk over time.** At each year, RiskScape™ calculates the risk for each year for the hazard layers. For this case study, the hazard data does not change over time but, if there were a climate-change element or other temporal element to the hazard data, this could also be included so that, at a given year, both the exposure and hazard data would vary.

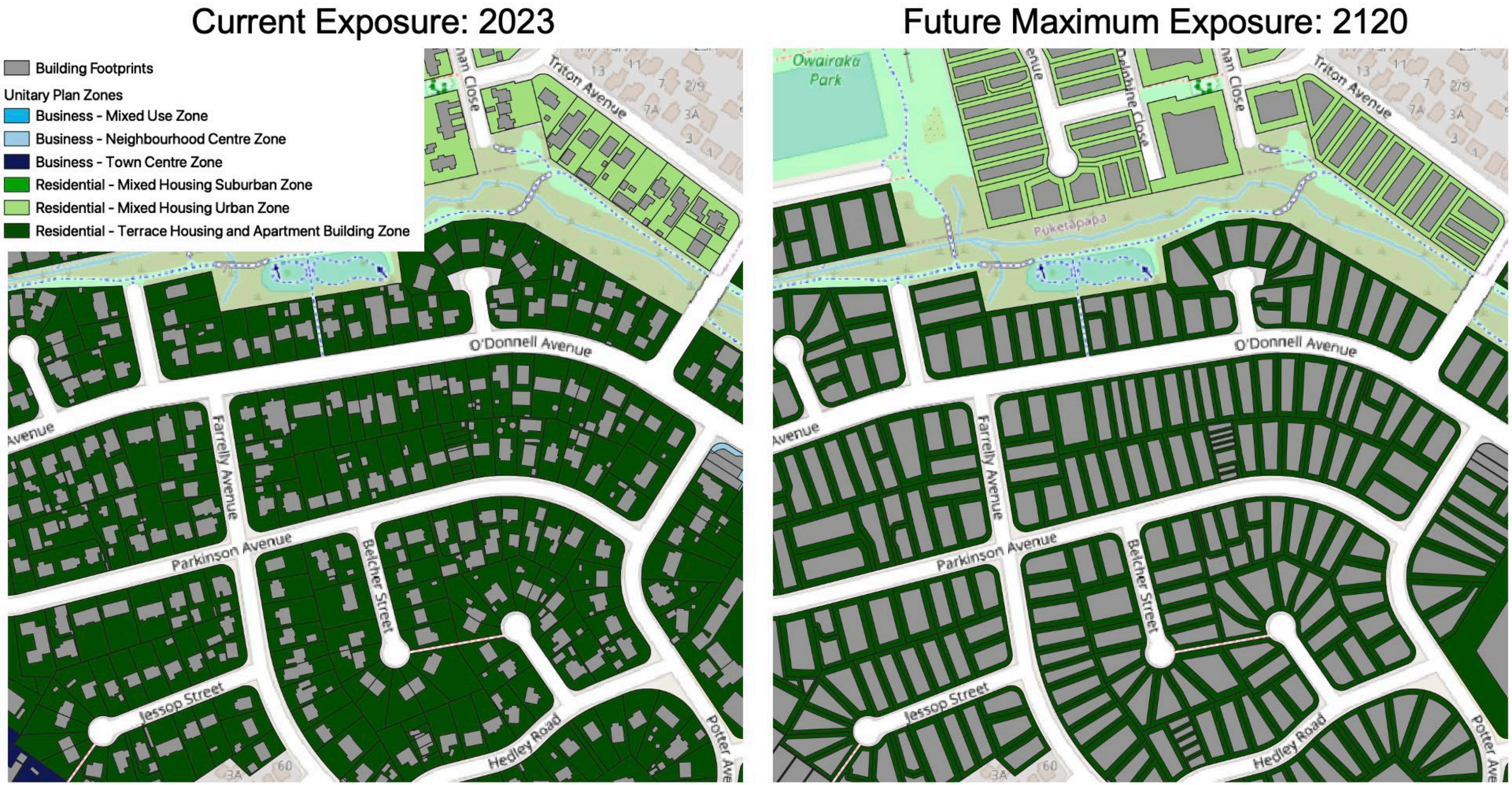

Figure 3.9 Exposure models defining the current exposure (2023) and future maximum exposure under the permitted development activities.

The RiskScape™ modelling outputs are defined in two metrics (Figure 3.10). The top panel shows risk curves that show the AEP (%) for 2023 of exceeding a certain level of loss (x-axis). The lines represent different mitigation options. The bottom panel shows mitigation options: baseline – do nothing, which allows intensification with no mitigations; AEP% + freeboard; and add freeboard (e.g. 300 mm height); specifying a fixed floor height (e.g. 1000 mm). This example is cumulative for the buildings within the flood plain, but this could also be generated for a single building, site or any other scale.

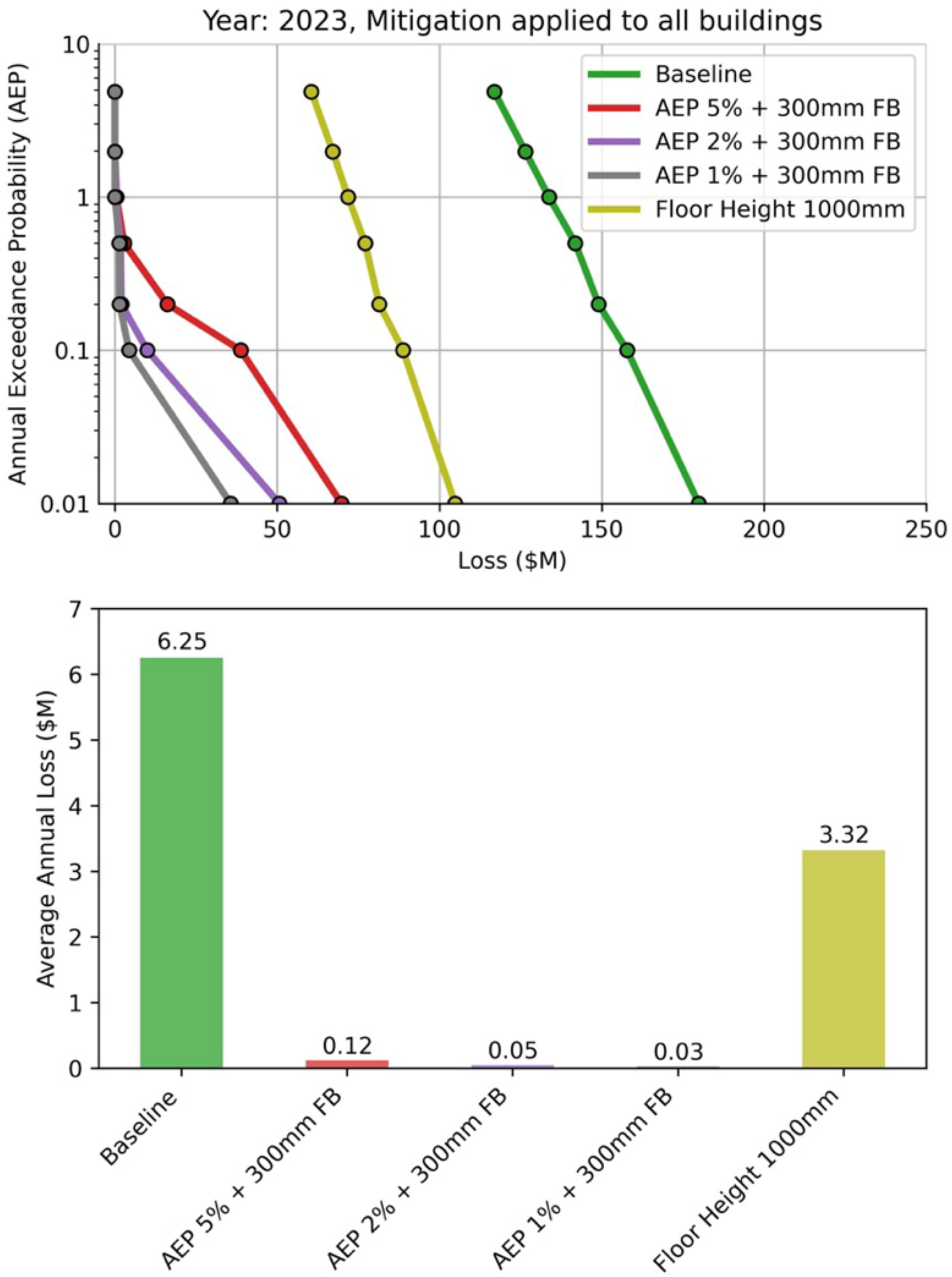

Figure 3.10 Results from RiskScape™ for current exposure with various mitigation scenarios.

Figure 3.10 shows that loss can be reduced by using different mitigation options. Setting the floor height to a fixed value of 1000 mm reduces the loss. However, it is not as beneficial as linking it with AEP plus freeboard. This is because different flood depths will be experienced on different properties – for some, this may equate to 1000 mm but could be 1200 mm or 700 mm for others. There is also reduction in losses when applying the 5%, 2% or 1% AEP flood plus freeboard model.

In the bottom panel of Figure 3.10, the AAL risk metric is shown. AAL is the estimated annual loss averaged over many years. This metric can be used in cost-benefit analysis. In the annualised risk, it is evident that there is a reduction of loss through any floor raising linked to any of the flood levels.

Mitigation options can be modelled for new buildings when 20% of a case study area is intensified. The top panel of Figure 3.11 shows the risk curves for AEP that are output from the RiskScape™ modelling, and the bottom panel shows the impact of different mitigation options on AAL, revealing that reduction in losses can be achieved when applying different mitigation options in this scenario.

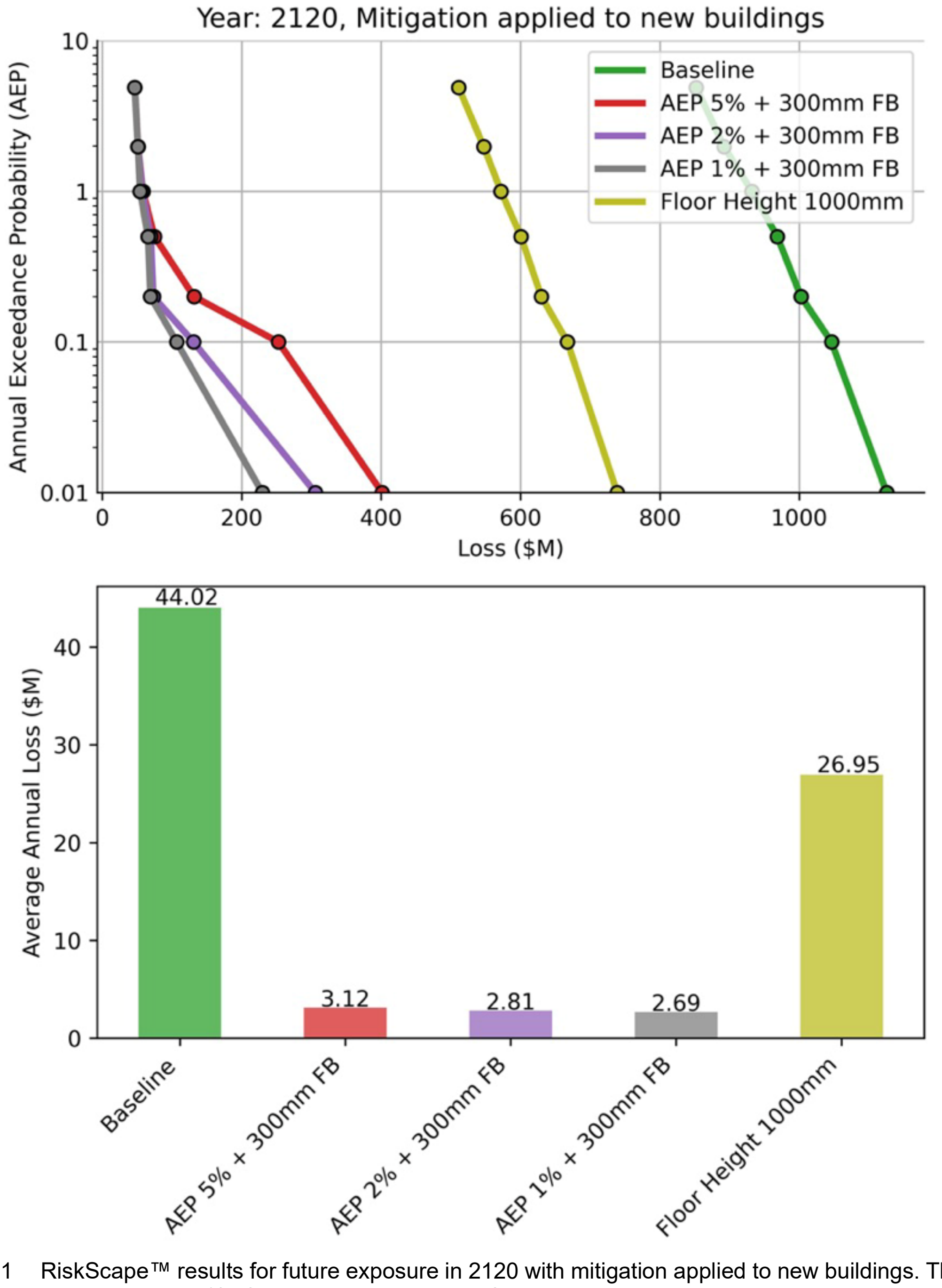

Figure 3.11 RiskScape™ results for future exposure in 2120 with mitigation applied to new buildings. This model assumes that 20% of land parcels are intensified.

Another output from RiskScape™ is the aggregated risk at different levels – the total risk for all properties within a given polygon. For this case study, risk can be aggregated to each of the development polygons (Figure 3.12). This aggregation allows for existing development or natural boundaries to be utilised to identify areas where mitigation measures could be applied to address a specific risk level that is beyond the tolerable threshold. In this example, an AAL of 0.1% of the total value of buildings is set as being tolerable. Red polygons (Figure 3.12) are at the highest risk category, and some further interventions could be applied to these, while grey polygons demark tolerable risk. This AAL of 0.1% is set as a hypothetical value used only for demonstration purposes.

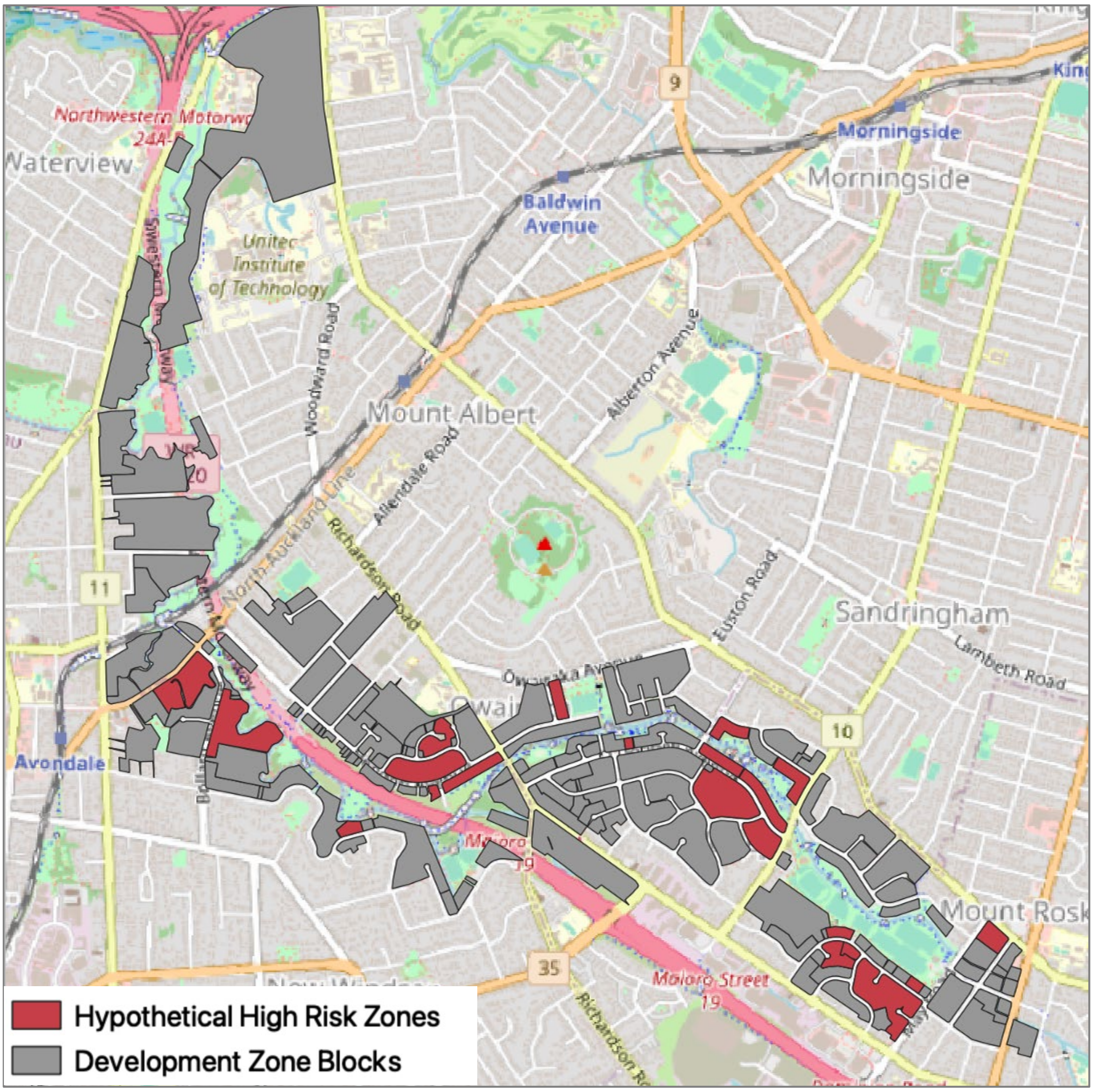

Figure 3.12 Map showing development areas, with a risk above 0.1% average annual loss noted in red. These areas are used to identify where reduce (retreat) and avoid (no intensification) mitigation measures are applied.

In Figure 3.13, the scenario for 'no intensification' in high-risk zones shows a reduction in AAL ($6.39 million, or 15%), as does retreating from high-risk areas ($7.51 million, or 17%).

These results can now be compared with the mitigation options of taking an event magnitude and adding a freeboard to this ($40.9–$41.33 million, or ≈93%). A combined option includes applying minimum floor heights over 1% AEP to some new buildings, and retreat from high-risk zones reduces the AAL more than the individual policy interventions ($41.66 million, or 94.6%).

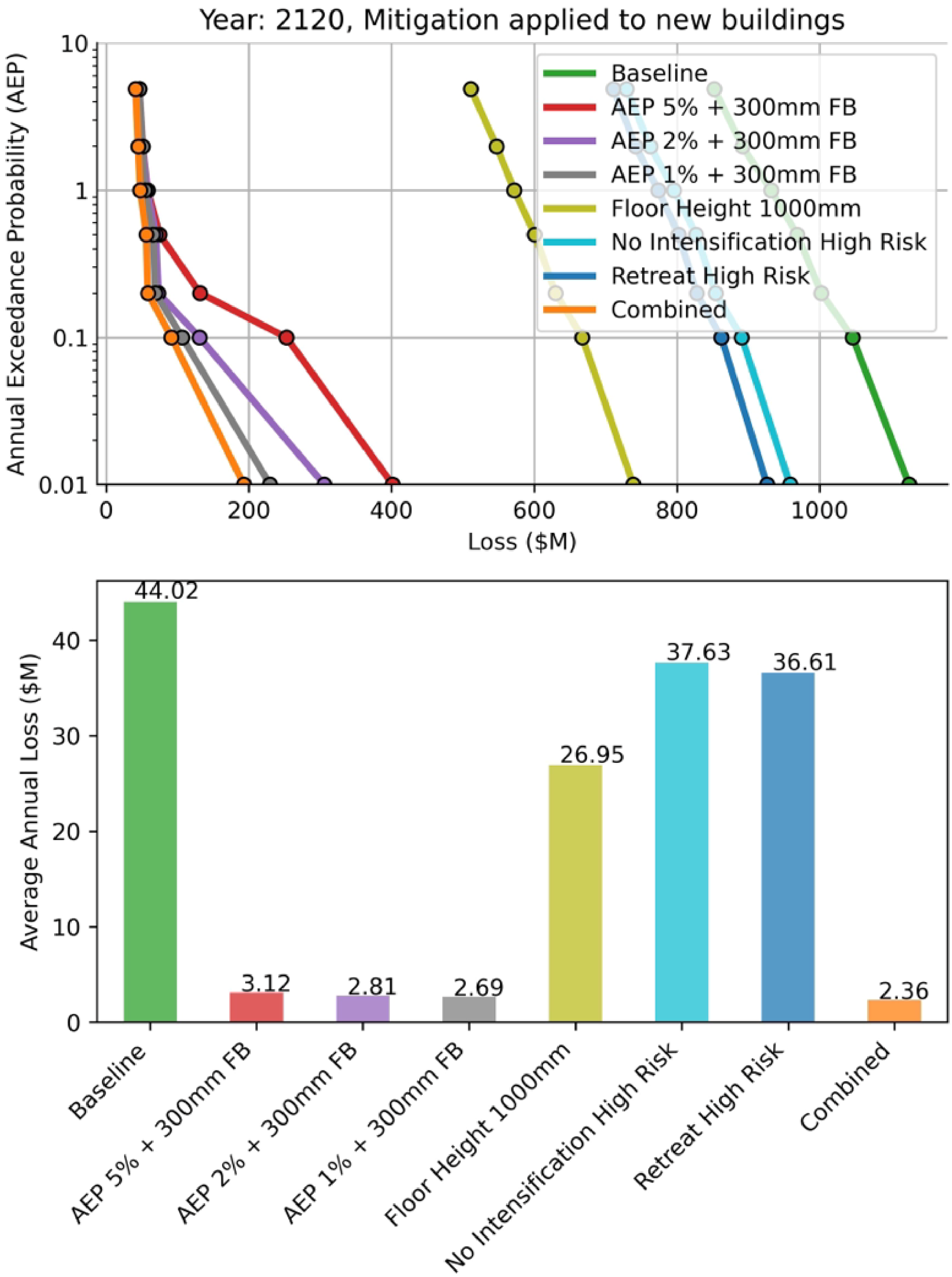

Figure 3.13 RiskScape™ results for proposed mitigation options, such as raising floor levels and restricting intensification and retreat in high-risk areas, as well as a combination of retreat in high-risk areas and raising floor levels to 1% AEP + 300 mm freeboard in other areas.

3.4 Climate Change

3.4.1 Location and Policy Context

Orewa is a suburb on the northeast coast of the Auckland region and was selected to demonstrate an assessment of the change in risk due to climate change and intensification. The case study also shows the identification of relative contribution and mitigation options. Orewa has experienced significant development over the last two decades, with both greenfield development and intensification through infill and permitted height increases. Further context on previous adaptation approaches to coastal erosion in Orewa are found in Appendix 5.

The current land-use types and permitted activity levels for development are detailed in Tables 3.1 and 3.2. For the purposes of this case study, any potential further development through PC78 has not been considered, only the currently operative provisions. Further development is possible through the resource consent process; however, due to the myriad of possibilities, the permitted activity level has been used in this case study to assess the baseline level of risk. The Residential – Terraced House and Apartment Building zone does not have a permitted activity for residential dwellings. The standards for the restricted discretionary activity have been used as a proxy for permitted activity standards, with three dwellings, as the zone is intended to be the most intensive – it is reasonable to assume at least as many dwellings as in the lower intensity zones.

The Business – Mixed Use and Business – Neighbourhood Centre zones permit residential dwellings, usually only applying a height standard. Vehicle parking may be provided, but is not required, and building coverage is anticipated to be maximised to make the most efficient use of the land. The impervious and building-coverage areas have been estimated and are higher than the most intensive residential zone. The Business – Town Centre zone has a contextual height setting; the midpoint of that range has been used for this modelling. These centres are limited and have a more commercial direction than the neighbourhood and mixed-use zones; as such, a higher building coverage and impervious surface percentage has been assumed.

Table 3.1 Permitted activity standards for the residential zones in the Auckland Unitary Plan.

Zone	Dwellings	Storeys	Maximum Impervious	Maximum Building Coverage
Residential – Single House	One dwelling plus one minor dwelling (65 m^2)	2	60%	35%
Residential – Mixed Housing Suburban	Three dwellings	2	60%	40%
Residential – Mixed Housing Urban	Three dwellings	3	60%	45%
Residential – Terraced House and Apartment Building	Three dwellings	4	70%	50%

Table 3.2 Permitted activity standards for some of the business zones in the Auckland Unitary Plan.

Zone	Storey (m)	Dwellings	Impervious Area	Building Coverage
Business – Mixed Use Zone	18	20	80%	60%
Business – Neighbourhood Centre Zone	11	10	80%	60%
Business – Town Centre Zone	21	20	90%	80%

3.4.2 Hazards Identified and RiskScape™ Modelling

Adapting to climate change at a local level can be done through land-use planning. This case study demonstrates how RiskScape™ can be used to identify areas of high future risk, which then inform adaptation options to manage risk from climate change in the future. The following process was undertaken to create a RiskScape™ pipeline to assess this:

- **Source hazard data.** Coastal inundation maps for Aotearoa New Zealand developed by NIWA (National Institute of Water & Atmospheric Research) were sourced. These are nine AEP events of coastal inundation, and sea-level rise increments of 10 cm from current sea level to 2 m sea-level rise are considered (Paulik et al. 2023). The sea-level rise projection is linked to Shared Socio-economic Pathways (SSP)[4] found on the NZSeaRise website[5], which contains estimates of sea-level rise across Aotearoa New Zealand annually from 2023 to 2150 with medium confidence.
- **Derive future growth potential.** By using the permitted activity enabled through the AUP (Figure 3.14, left; Tables 3.1 and 3.2) and overlaying the existing land parcels[6] (Figure 3.14, middle), RiskScape™ combines these two layers to assign development areas and permitted activities to each land parcel (Figure 3.14, right).
- **Create a future maximum exposure layer** that represents building footprints if maximum intensification was realised using RiskScape™. This includes maximum site coverage and maximum number of storeys. Figure 3.15 shows the current exposure and future maximum exposure.
- **Identify what percentage of land parcels are intensified by a future time horizon.** For this case, a final development date of 2120 is selected. RiskScape™ will create new exposure models for each year from the present to 2120, by which time 100% of permitted intensification is realised (Figure 3.16).
- **Define the risk metric** – for this case study, the re-instatement cost for buildings is used. This includes the AAL and event loss for a given AEP. In this case study, the change in risk over time due to climate change (sea-level rise) and different land-use planning policies is demonstrated.

4 The Intergovernmental Panel on Climate Change (IPCC)'s 6th Assessment Report (2021–22) shifted to a new core set of future representative scenarios based on SSPs. These comprise different socio-economic assumptions that drive future greenhouse gas emissions. The scenarios span a wide range of plausible societal and climatic futures, based on greenhouse gas emissions, that result in the stabilisation of global warming at 1.5°C to over 4°C warming by 2100.

5 https://www.searise.nz/

6 Existing land parcels are available from Land Information New Zealand for all of Aotearoa New Zealand.

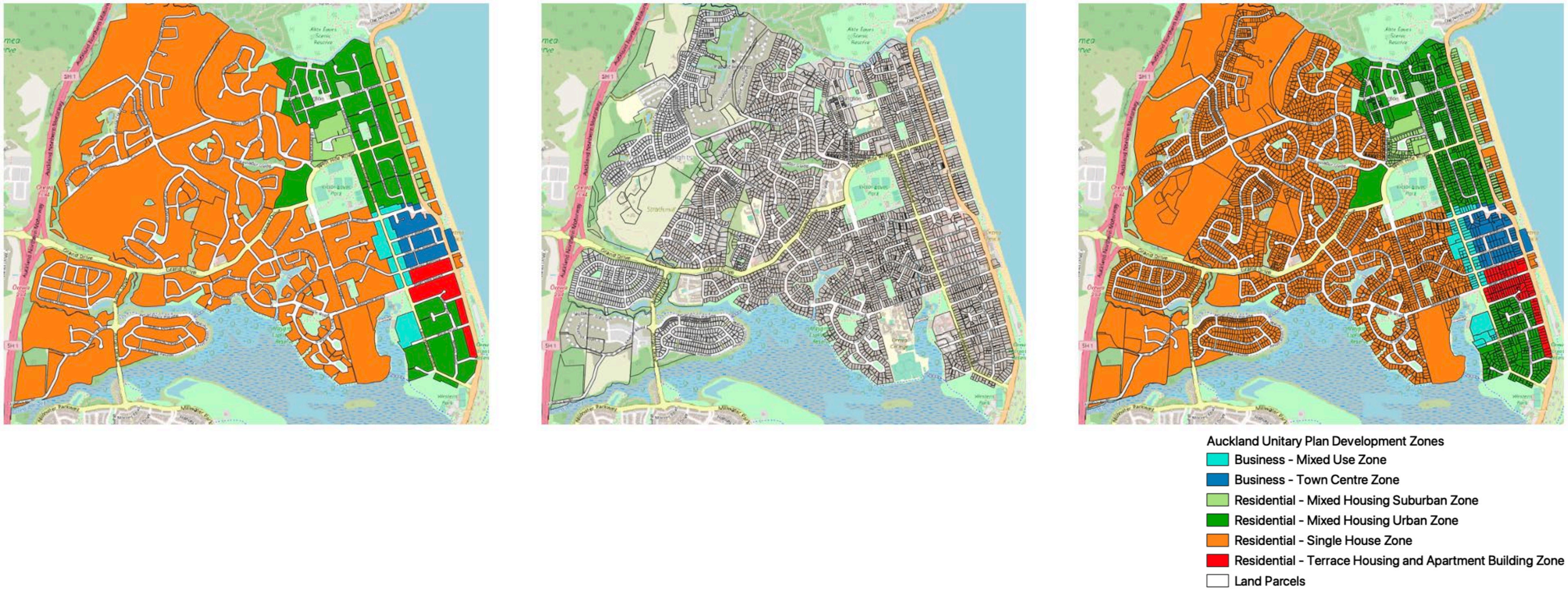

Figure 3.14 Map showing Auckland Unitary Plan current development potential (left), land parcels (centre) and potential development (right).

Current Exposure (2023) | Future Maximum Exposure (2120)

Figure 3.15 Current exposure in land parcels (right) and future maximum exposure (2120) with intensification of every parcel.

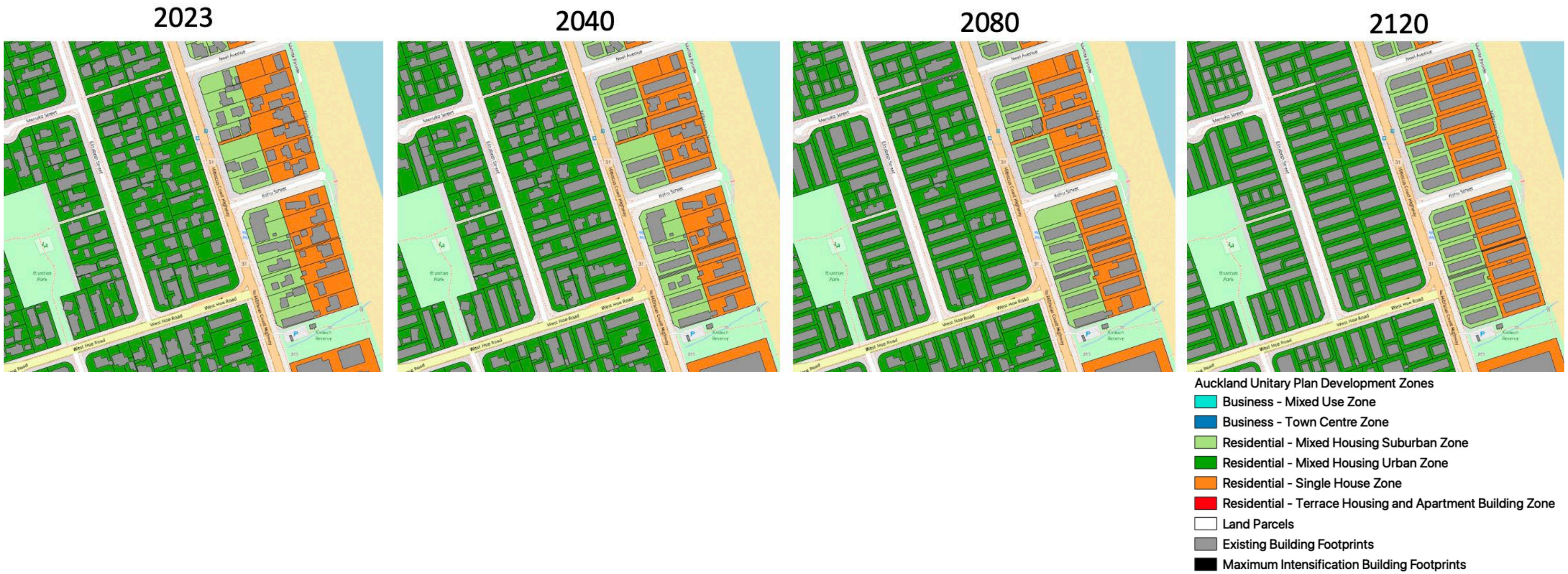

Figure 3.16 Example of dynamic exposure model from current exposure in 2023 to future exposure in 2120. This projection assumes an intensification rate of 100% (every land parcel is intensified).

Some of the outputs from this assessment are shared below. Firstly, the change in risk from coastal inundation from 2023 to 2120, with no intensification, for five SSPs (Figure 3.17). There is uncertainty within a given SSP in terms of the future sea-level rise, and this is reflected in the uncertainty in the future risk. The results show that the mean future risk from different SSPs could vary from $12 to $63 million by 2120, depending on which SSP is followed.

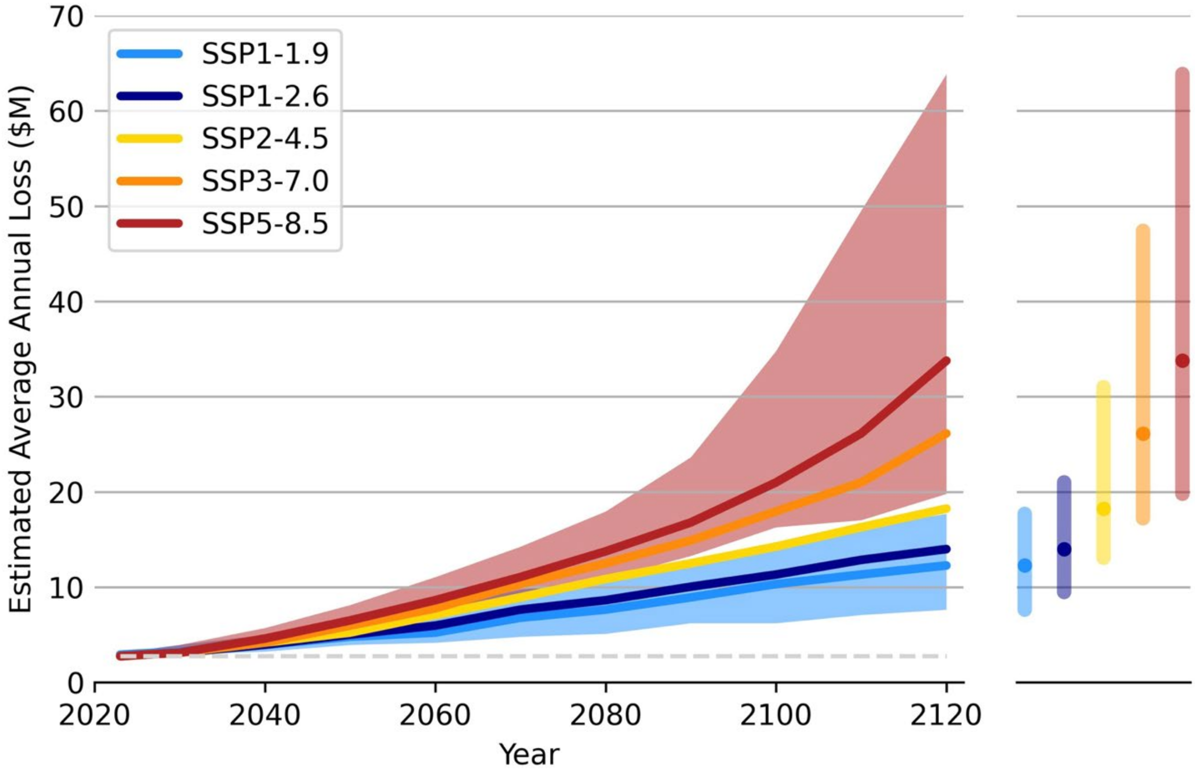

Figure 3.17 Future risk expressed as average annual loss for current exposure (2023) for five different Shared Socio-economic Pathways (SSPs). The uncertainty range (90^{th} percentile confidence interval) over time is only shown for two SSPs, but the uncertainty in future risk at 2120 is shown for all SSPs in the right part of the figure. The mean risk is shown as a bolder dot in each SSP uncertainty band.

- **Choose a single SSP.** In this case, SSP1-2.6 (the agreed pathway under the Paris Agreement) was chosen to explore the impact of intensification on risk (Figure 3.18). The results show that, by 2120, the future risk could have increased from ~$4 million to over $100 million due to increased intensification using the current permitted activities in the AUP.

By undertaking the risk analysis with climate change and growth separately, the relative contribution between different climate-change scenarios and intensification scenarios can be used to see what is contributing to future risk over time. In this example, it shows that, in each scenario, the majority of the future risk by 2120 results from increased intensification (Figure 3.18).

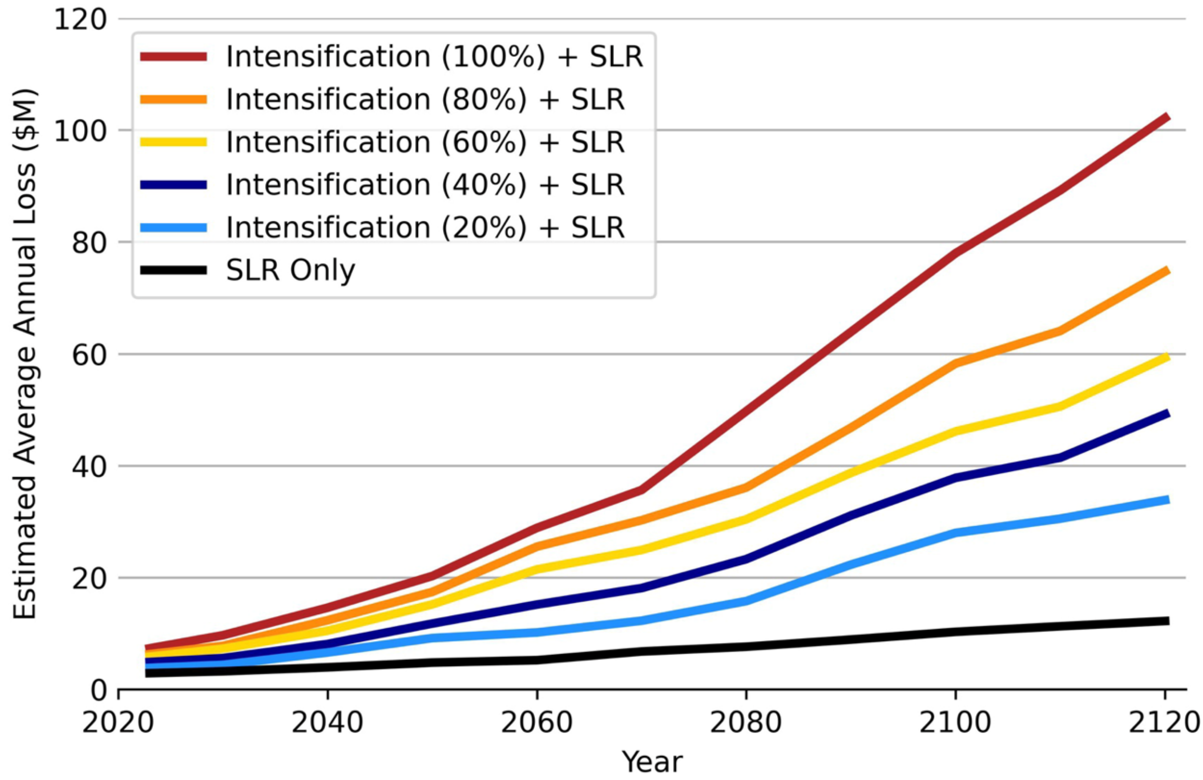

Figure 3.18 Future risk from coastal inundation, with sea-level rise expressed as average annual loss for SSP1-2.6 for different intensification rates. The black line is the baseline with no intensification.

- **Incorporate the impact of adaptation measures.** The results at year 2120 from the model, which used SSP1-2.6 and 100% intensification, is aggregated to each development parcel.
- **Set a risk threshold** that defines areas that have an unacceptable level of risk. In this example, a hypothetical risk threshold is used for any areas that have an AAL above 0.1% of the value of the buildings per year – the risk is intolerable (Figure 3.19, left). The dollar values use 2023 costings.
- **Modify RiskScape™ inputs to reflect different adaptation policies.** In this case, these were retreat from the high-risk areas and restriction of intensification in high-risk areas. A 20% intensification rate was adopted. Figure 3.19 (right) shows areas of no further intensification in grey and retreat zones in green, with the remainder of the existing zoning and permitted intensification unchanged.

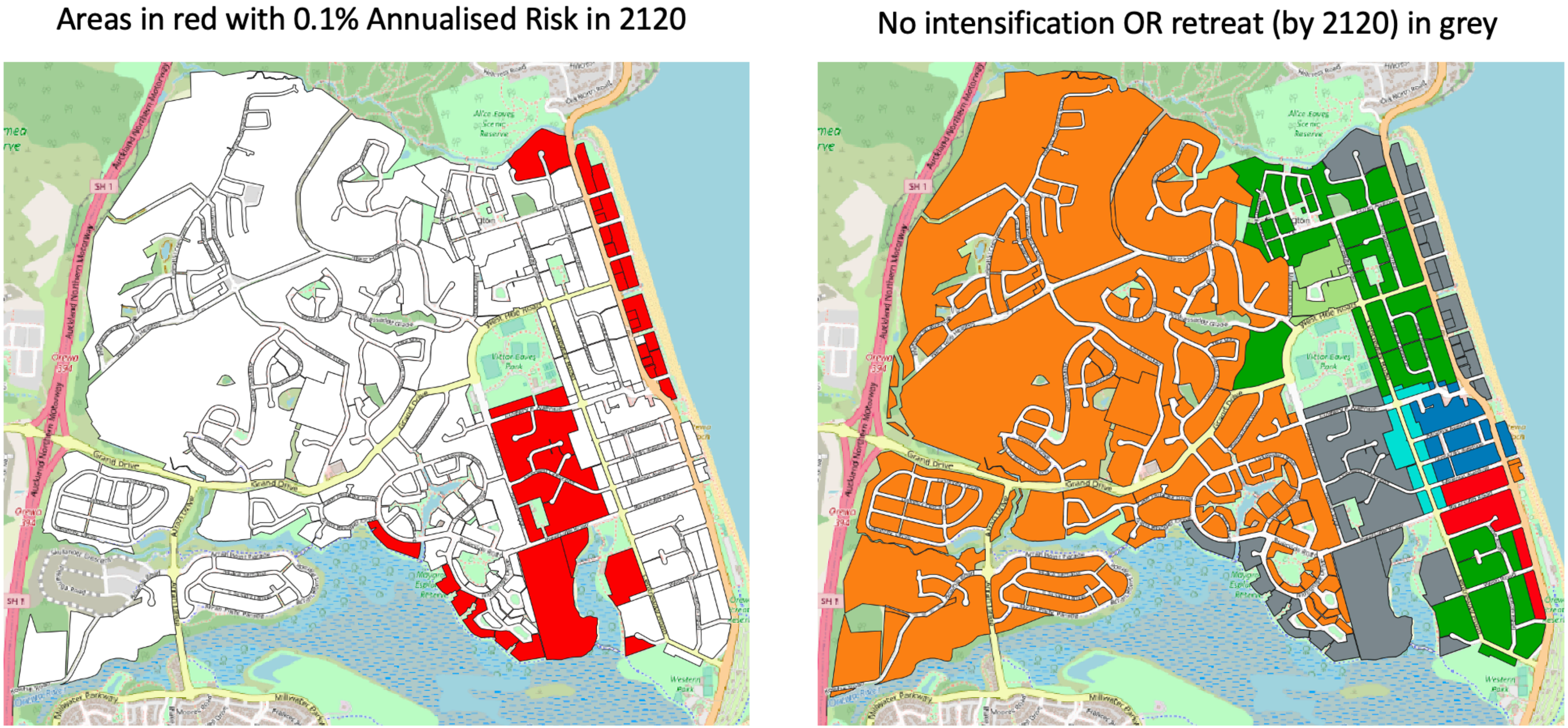

Figure 3.19 Areas of high risk (annualised risk of over 0.1% of the replacement value of property) in red on left. Modification of development potential, where high-risk areas are restricted from intensification or retreat occurs, is a land-use planning response.

The results shown in Figure 3.20 indicate that avoiding intensification in the high-risk areas has a similar level of risk increase to that from climate change alone. However, retreat from high-risk areas, while still allowing intensification in other areas, leads to a projected reduction in risk.

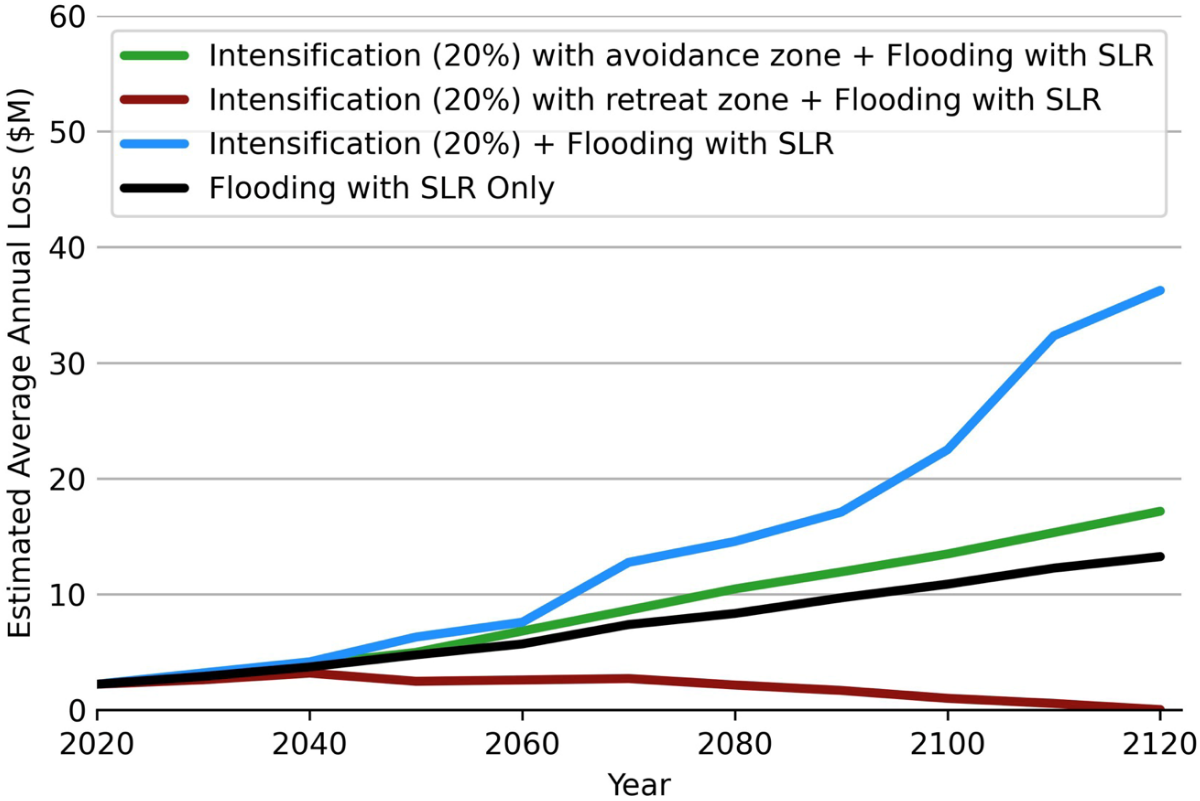

Figure 3.20 Example of SSP1-2.6 with 20% intensification (blue) and mitigation either through restricting intensification (green) or retreat (dark red) from high-risk areas.

3.5 Dynamic Adaptive Policy Pathway

3.5.1 Location and Policy Context

The aim of this case study is to demonstrate how risk analysis in RiskScape™ can be used to assist in developing a DAPP process with a focus on trigger points.

DAPP is an internationally recognised approach, supported by the Ministry for Environment, for undertaking adaptation planning (Figure 3.21). The process consists of having a number of pathways, signals, thresholds and triggers. Signals represent a warning that adaptation needs to be considered (e.g. sea-level rise reaches X cm above a particular datum). Triggers represent the occurrence of a situation where a decision needs to be made to transfer to a new pathway. The key driver is to make the decision and change pathways before inconvenience becomes too great for those affected, or investment and cost-benefit no longer deliver value. This concept has been embedded in the coastal hazards and climate change guidance for local government (Bell et al. 2017).

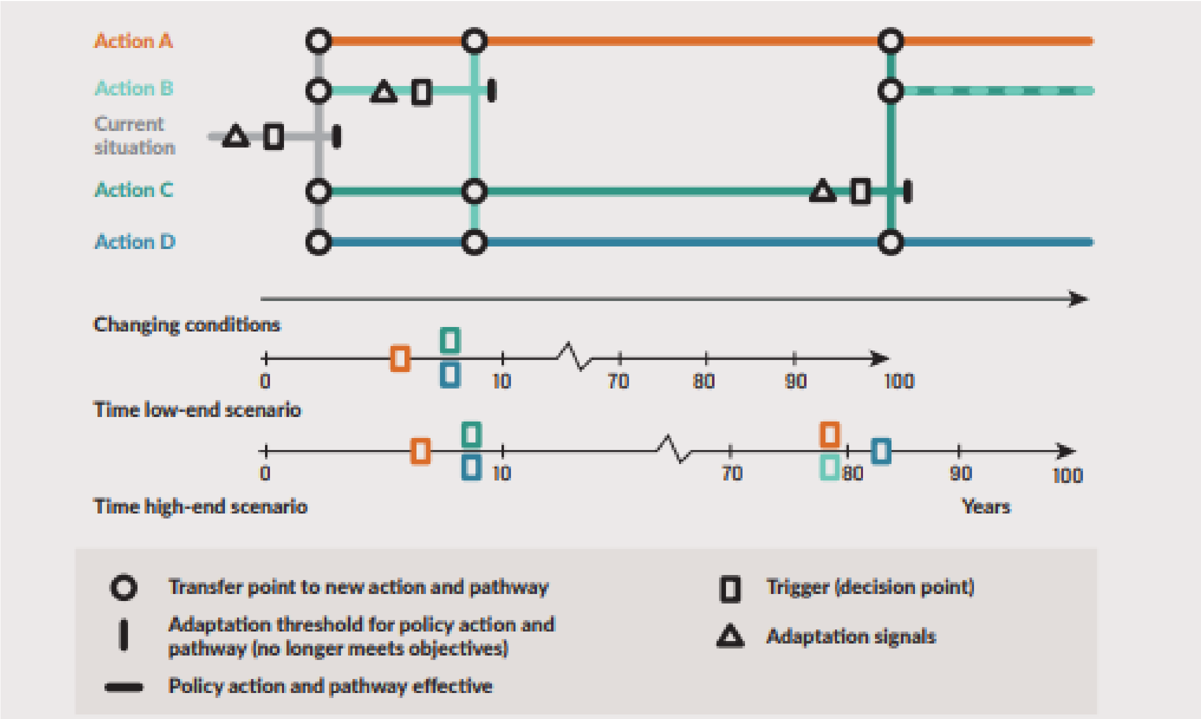

Figure 3.21 Schematic of a Dynamic Adaptive Policy Pathway, showing pathway, signal, threshold and trigger actions (RMRP 2020).

The application of a DAPP in a coastal context, focusing on consequences against a range of timeframes and hazard scenarios, can be used to develop adaptation pathways. These can include accrued benefits, for example, where the lifting of a road might provide erosion protection, and vulnerabilities, where that road lifting might increase inundation risk to properties behind it, and also tipping points, such as the road being closed for more than five days a month at high tide to design pathways and triggers. This can allow adaptation to occur before the tipping point or threshold is reached (Stephens et al. 2017).

Maraetai is coastal settlement in the southeast of Auckland. Maraetai Drive runs along the waterfront, with residential dwellings landward of the road. Auckland Transport has been investigating levels of service provided by Maraetai Drive in conjunction with climate-change scenarios to build a series of triggers (Table 3.3) that could then be used to commence community engagement to guide discussion on adaptation. The analysis undertaken is not intended to be a full DAPP process.

3.5.2 Hazards Identified and RiskScape™ Modelling

RiskScape™ can be used to model proposed trigger points to help evaluate their suitability. Trigger points developed by Auckland Transport were used to inform this case study (Table 3.3).

The following process was undertaken to develop a RiskScape™ pipeline:

- **Source hazard data.** In this case, the coastal inundation maps for Aotearoa New Zealand, developed by NIWA, were used. These are for nine AEPs and include sea-level rise increments of 10 cm from current sea-level to 2 m sea-level rise (Paulik et al. 2023). The sea-level rise projection is linked to SSPs found on the NZSeaRise website, which contains estimates of sea-level rise across Aotearoa New Zealand annually from 2023 to 2150 with medium confidence. This allows the risk from changing hazards over time, as caused by climate change, to be modelled in RiskScape™.

- **Incorporate risk metrics.** RiskScape™ was used to model three risk metrics linked to each of the three trigger points in Table 3.3.
- **Incorporate triggers.** RiskScape™ was used to estimate the mean number of repair days per year, the mean repair cost per year and the number of properties that may have access affected per year. These risk metrics are modelled for every year from 2023 to 2120 (the hypothetical planning horizon) for different SSPs.

The top panel of Figure 3.22 shows the estimated average number of days per year that Maraetai Drive could be under repair under three of the SSPs per year between 2023 and 2120. The repair days increase at a similar rate for the different SPPs until ~2040. This changes beyond 2040, with the greater SSPs having a greater increase in the number of repair days. The trigger point of six repair days per year in the DAPP is estimated to occur between 2065 and 2085, depending on which SSP is followed.

The middle panel of Figure 3.22 shows the ratio of estimated average repair cost to replacement cost for different SSPs. The model estimates the long-term average annual repair cost increases from just under 1% to just over 1% of the renewal cost, then to 2–4% by 2040. The ratios diverge further beyond 2040. The risk metric used is only the AAL, which is the long-term annual repair cost. In any given year, this could be much larger or smaller depending on what coastal inundation events occur. Nonetheless, the annual repair cost, the trigger in this case, is not likely to be reached at 70% of the value. The trigger may need to be reconsidered.

The bottom panel of Figure 3.22 demonstrates the number of days per year that access to approximately 30 properties in the case-study area will be affected over time for SSP2-4.5. The certainty of the hazard and SSP is reflected in the result band width. The results show that at least 10 properties a year will be affected in 2023, and as many as 25 could be affected every year. By 2060, there is a high likelihood that the majority of properties will have their access affected every year by 2060. This is linked to the life-safety trigger, as the road would become dangerous to pass if it is flooded.

Table 3.3 Summary of potential signals/triggers/thresholds for roads, provided by Auckland Transport. Note: Rainfall flooding was not able to be modelled within the scope of this case study. MHWS = mean high water springs.

Coastal Inundation		Coastal Erosion		Rainfall Flooding	
Description	**Commentary and Potential Thresholds**	**Description**	**Commentary and Potential Thresholds**	**Description**	**Commentary and Potential Thresholds**
Asset					
Sea-level rise reaches X mm above MHWS.	Sea-level rise during MHWS exceeds road surface level by 0.2 m.	Erosion within X m of asset.	Erosion within 2 m of a road.	Bank erosion within X m of asset.	Erosion within 2 m of a road.
Maintenance costs exceed $X pa for protection works.	When maintenance cost (last three years) = 70% of renewal cost. For a given level of flooding, the level of damage is variable based on the design of the assets. Assets can be designed to be underwater occasionally.	Maintenance costs exceed $X pa for protection works .	When maintenance cost (last three years) = 70% of renewal cost.	Maintenance costs exceed $X pa for protection works.	When maintenance cost (last three years) = 70% of renewal cost. For a given level of flooding, the level of damage is variable based on the design of the assets. Assets can be designed to be underwater occasionally.
Service Delivery					
Duration of outage exceeds X amount of time.	Potentially 6x per annum for eight or three hours either side of MHWS. Triggers should be aligned with the response times by road maintenance classification.	-	-	Duration of outage exceeds X amount of time.	Triggers should be aligned with the response times by road maintenance classification.
Health and Safety					
Public safety is approaching an unacceptable level due to the number of inundation events occurring X times each year, making the road dangerous to pass.	-	Public safety is approaching an unacceptable level due to the number of undermining events occurring each year.	-	Public safety is approaching an unacceptable level due to flood events occurring X times each year, making the road dangerous to pass.	-

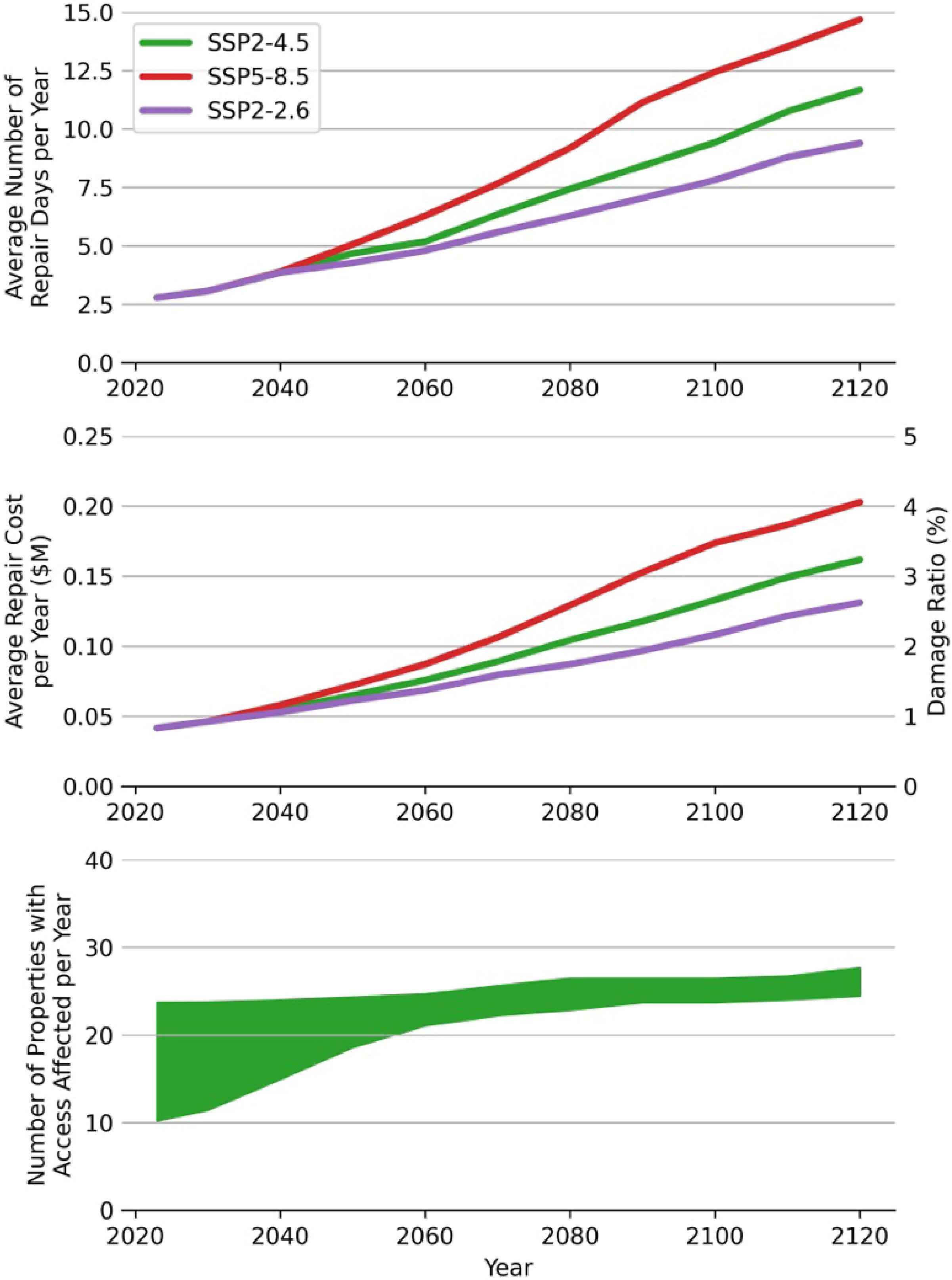

Figure 3.22 Example of RiskScape™ results for three different risk metrics.

Figure 3.23 shows the same graphs as Figure 3.22 but for SSP2-4.5, with uncertainty represented. This shows how uncertainty in a specific risk metric changes over time, with uncertainty increasing over time.

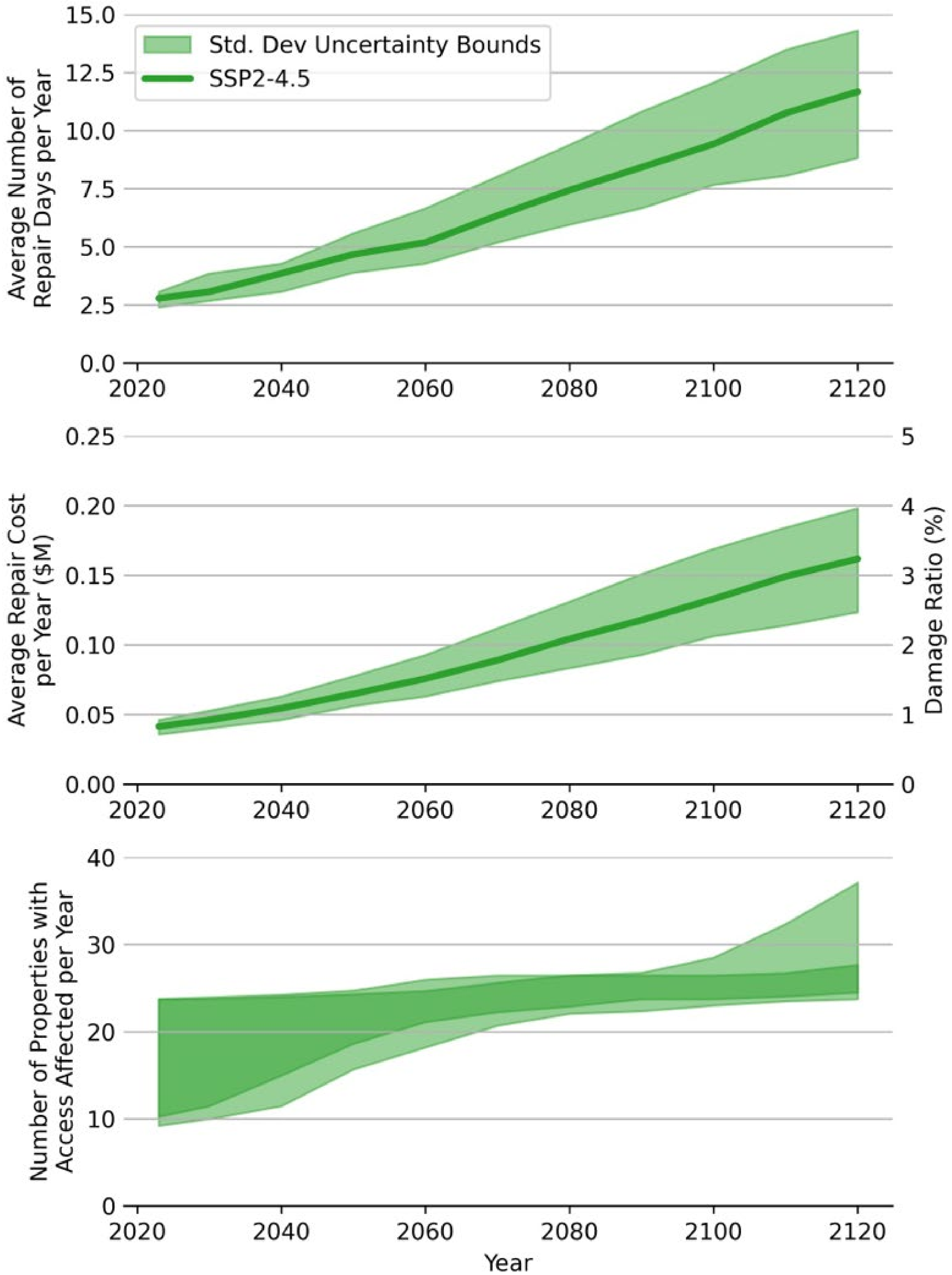

Figure 3.23 Example of RiskScape™ results for three different risk metrics for SSP2-4.5, with uncertainty shown (90th percentile confidence interval).

4.0 DISCUSSION

4.1 Ability to Replicate

Across Aotearoa New Zealand, communities are grappling with how to address climate-change and natural-hazard impacts. There is a need to make evidence-based decisions in a timely manner. RiskScape™ modelling provides a robust and flexible mechanism to provide appropriate evidence, supporting decision-makers when assessing viable land-use planning options. The focus of these case studies has been to provide exemplars of the capability of RiskScape™, and develop the pipeline code, such that this analysis could be undertaken anywhere in Aotearoa New Zealand with data and parameters relevant to the area of interest.

In the following subsections, ways and places in which these case studies could be replicated are discussed, as well as limitations of these uses.

4.1.1 Multi-Scale, Multi-Hazard

RiskScape™ modelling can be applied across multiple scales (local, regional, national) to provide quantitative information for contextual decision-making. The examples within this report highlight case studies for discrete locations but consider specific hazards, climate-change scenarios, risk thresholds, and current and potential land-use planning directions to demonstrate how RiskScape™ can be used.

While the DAPP case study (Section 3.5) only examines one hazard, this could be expanded to include multiple hazards in this area to better refine triggers, thresholds and pathways as part of a comprehensive DAPP process. The DAPP framework can support and provide tangible benchmarks to inform the conversation around various types of adaptations, including hard protection works.

The climate-change case study (Section 3.4) considers different SSPs overlaid with multiple future development scenarios, such as intensification or retreat from areas. This could be replicated with different permitted activity levels or different risk thresholds. The case study enables the risk from intensification in different areas to be understood.

This case study demonstrates that a reduction of risk can be achieved while still allowing for intensification. This type of assessment could be used by councils to support plan development processes, to inform decision-making on climate-change adaptation and to mitigate against future maladaptation. Part of risk assessment is setting a threshold for tolerability or acceptance of risk. This is something that councils are responsible for and may vary from hazard to hazard. Thresholds have been hypothetically set for these case studies for demonstration purposes. RiskScape™ allows thresholds to be changed to understand how this impacts on the overall risk assessment.

The Spatial Planning Act 2023 requires regional spatial strategies to be developed, which may include the type of assessment undertaken in the greenfield case study (Section 3.2). Being able to assess the potential hazard risks across a region may enable direction on land-use change over the next 30 years to be undertaken. The approach in this case study could also be used to fulfil NPS-UD obligations.

The PARA case study (Section 3.3) shows how councils could use RiskScape™ to fulfil their NPS-UD and Medium Density Residential Standards (MDRS) obligations to continually supply sufficient residential zoned land. The NPS-UD requires continuous assessment to ensure that there is sufficient residential and commercial land available now and into the future. Understanding risk, and the potential to intensify in low-risk areas and avoid higher-risk areas or re-evaluate the effectiveness of mitigation and risk reduction measures, is crucial to providing that continued supply.

The cost-benefit analysis that is produced as part of RiskScape™ has many uses. It is required as part of plan preparation under the RMA (Schedule 1) and is used extensively for business case development and asset management planning, including adaptation option analysis and political decision-making.

4.1.2 Communication and Engagement

The RiskScape™ framework can be used to support community and stakeholder engagement, empowering communities to provide input into the decision-making process, while also providing contextual values for the modelling process. Through community engagement, it is possible to prioritise options and engage with the community who are invested in any proposed planning changes. As hazards, risks and society are evolving, solutions need to be adaptable as well. The RiskScape™ framework provides this adaptability, enabling inputs and directions to be changed to reflect this evolution.

The RiskScape™ outputs can be used to communicate the change in risk metrics over time and express uncertainty around climate-change scenarios. However, it can also be used to demonstrate that there is a level of certainty. The DAPP case study shows that at least 10 houses are affected now, and there is a 90^{th} percentile confidence that at least 20 hours will have disrupted access by 2060. This type of output can make engagement much more meaningful for communities than regional- or national-scale models.

4.2 Limitations and Uncertainties

Hazard and risk modelling will always be limited by data availability. Councils must be prudent in their spending, and, as such, often only have data available that is specifically related to an asset or policy direction. These case studies used data available from Auckland Council, supplemented with externally provided flood data sourced from Ambiental, and national models such as the GNS Science Active Faults Database, GNS Science Landslide Database, GNS Science Landslide Susceptibility model and NIWA Coastal Inundation model.

National models may have scaling issues when attempting to apply these at a local level and are often only appropriate for regional-scale assessment. The tsunami evacuation zones have been used for screening only, as they are not at a suitable scale for land-use planning.

An ongoing challenge when considering multiple hazards are inconsistencies in both likelihoods and hazard definitions. In the case studies undertaken here, some, such as flooding events, are expressed as AEP, whereas some geological hazards are expressed in recurrence intervals. The timescale for hazards also varies. Furthermore, some data may have hazard-intensity values (e.g. flood depth), while some are categorical data, such as susceptibility or binary outcomes (e.g. in or out of a tsunami evacuation zone). Understanding the spectrum of inputs and, if possible, reconciling them prior to replicating these case studies in other areas, will influence the way in which results can be used.

Modelling to understand the impact on risk from protection structures was not available for these case studies. This modelling is typically complex and expensive. For example, modelling scenarios for different hard protection structures along Te Auaunga / Oakley Creek would need to include impact on risk over time, including residual risk, a range of breach/failure scenarios and assumptions about maintenance. These elements, if known, could be incorporated into scenarios in the future.

When modelling ‘avoid’ scenarios. RiskScape™ is currently able to remove the building, and its related exposure, but there is no feature to model what the land parcel becomes. For example, if a residential dwelling is removed, and the site becomes a riparian margin / esplanade reserve, there is no way to account for the intangible value of that public space to the community in RiskScape™. The challenge with modelling such intangible values is that a monetary value is not able to be placed on them when considering potential cost-benefit analysis.

The land-use planning parameters used are based on permitted activity standards. It is unlikely that full development potential will be realised in all areas. Resource consent for further development beyond the permitted activity standard is also possible. There are also some zones in the AUP, such as the Residential – Terraced House and Apartment Building and the business zones, that either do not have a permitted activity standard for residential activity or permits them with different standards to the residential zones. This affects the maximum intensification possible input. In such cases, proxies have been developed. Further detailed information as to what building materials are commonly used in intensification development in the different areas was not considered. As a result, a generic 3–6-storey timber frame with concrete tilt-slab was used as the building typology for any intensification. The type of building material can have an impact on the risk for some hazards. For example, timber-framed residential dwellings are considered at lesser risk from fault rupture compared to concrete ones. Further work could develop location-specific building typologies for future exposure models using recent consents from councils to define common building typologies used in intensification.

As highlighted earlier, while many councils are moving to a risk-based framework for natural hazard management, acceptable/tolerable risk levels are still to be set by most councils. The case studies have used hypothetical risk tolerance thresholds to demonstrate how these could be incorporated. Risk tolerance, community versus national appetite for risk, who funds risk reduction, and recovery when that risk is realised, are all part of an ongoing conversation.

5.0 CONCLUSIONS

The purpose of this project is to demonstrate the capability of RiskScape™ for land-use-planning decision-making. This was undertaken in collaboration with Auckland Council to find opportunities for producing scientifically grounded outputs that may support their future work programmes. This project involved the development of four case studies:

1. Spatial planning options for greenfield sites.
2. Policy interventions for Te Auaunga / Oakley Creek, including spatial representations of PARA measures.
3. Climate-change interventions modelled for Orewa, which can inform future adaptation decision-making.
4. Dynamic Adaptive Policy Pathways (DAPP) for a road that provides access to residential properties in Maraetai.

The case studies demonstrated how RiskScape™ can and could be used as a risk assessment tool to manage the impetus and direction to understand risks from natural hazards, as well as to develop adaptation options. Case studies also show the capability of RiskScape™ to be replicable and for facets of the modelling to be changed to represent different options and scenarios. The case studies do not represent direction or recommendations for Auckland Council to implement any of the policy interventions and future directions modelled.

The outputs provided here can be used to support community consultation, plan development, asset management and resource consenting and political decision-making. The intention of making the outputs publicly available is for other councils to be able to replicate the process or be guided by the project.

The challenge remains for future studies to explore how decision-making using RiskScape™ occurs in the future. As we transition to new resource management legislation, there is opportunity for this to occur in Regional Spatial Strategy creation, as well as to support the implementation of other existing legislation.

6.0 DATA AND MODEL AVAILABILITY

RiskScape™ pipelines and input data (where already publicly available) used in the four case studies are available at https://github.com/GNS-Science/riskscape/tree/main/projects/land-use-planning-case-studies.

7.0 ACKNOWLEDGMENTS

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APPENDICES

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APPENDIX 1 LAND-USE PLANNING FOR NATURAL HAZARDS IN AOTEAROA NEW ZEALAND

Aotearoa New Zealand is a group of geologically diverse islands, perched across an active plate boundary, with some 15,000 km of coastline and many river systems. While this creates a physically stunning environment, it also presents a natural hazard risk when land is developed and used. The risk is compounded by the effects of climate change, now and in the future.

The risk from natural hazards, and the need to manage that risk, has been traversed by earlier papers, including Glavovic et al. (2010) and Saunders et al. (2007, 2013), Saunders and Beban (2012) and Saunders and Kilvington (2016). The Resource Management Act 1991 (RMA) requires local and regional authorities to control land for the purpose of avoidance or mitigation of natural hazards (s30 and s31), and s32 assessments[7] evaluate how this is achieved. Recent examples include Hutt City Council, Selwyn District Council and Te Tai o Poutini Plan[8] (the combined West Coast District Plan). The legislative context is summarised in Figure A1.1.

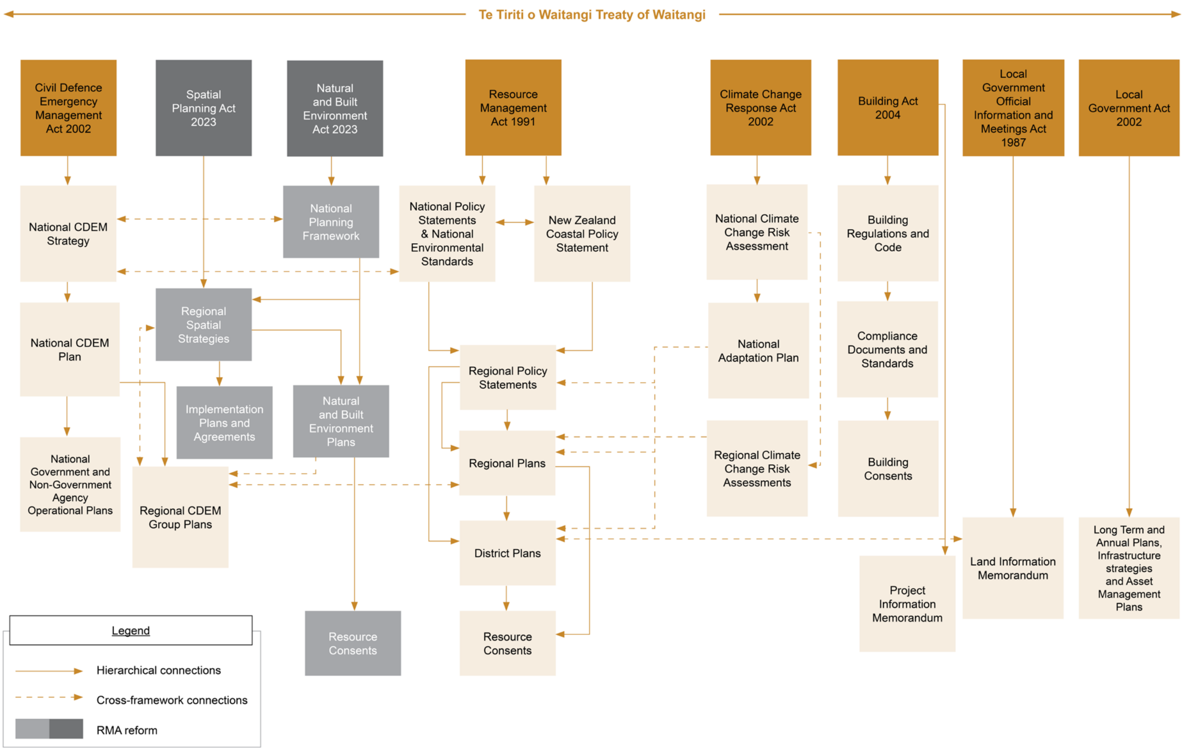

Figure A1.1 The legislative context for natural hazard management.

This report focuses on the way in which RiskScape™ could be used to meet councils' obligations under existing, and incoming, resource management legislation, using locations in Auckland as case studies.

The need for resource management reform and the way in which resource management could be more efficiently and effectively undertaken were both comprehensively detailed in the Resource Management Review Panel (RMRP 2020) report. The specific issues relevant to these case studies are:

7 Under the RMA, s32 evaluation reports are required to be prepared and published as part of plan development.

8 Note: Lead author developed the Te Tai o Poutini Plan provisions through to the proposed plan stage in their previous role.

- Aotearoa New Zealand is already experiencing the effects of climate change and associated threats to safety, and damage to infrastructure needs to be responded to with urgency.
- How ‘risk’ is understood and planned for in an effects-based resource management system.

In August 2023, the Spatial Planning Act and the Natural and Built Environment Act received royal assent. There are requirements within these Acts [SPA s.17.1.(i). and NBEA s.6(4)] that these case studies may fulfil.

There are other provisions related to natural hazards, climate change and council responsibilities, but these are beyond the scope of this report.

There are two other pieces of legislation still to be released, the National Planning Framework being one, which will bring together all of the existing national direction and contain future direction. Any future national policy statement for natural hazards would be contained in here. The third act to replace the RMA will be the Climate Adaptation Act, expected post-2023. It is reasonable to assume that adaptation plans, with robust assessments, will be required at a variety of scales.

Auckland was severely impacted by the Auckland Anniversary weekend floods and Cyclone Gabrielle, and some parts of West Auckland were still recovering from flooding during the previous winter. Several plan changes were paused following these events, including PC78.

PC78 is Auckland Council’s response to the government’s National Policy Statement for Urban Development (NPS-UD) and the requirements of RMA. The proposed changes to the Auckland Unitary Plan (AUP) seek to incorporate the Medium Density Residential Standards as outlined in Schedule 3A of the RMA. The changes also give effect to the NPS-UD, which includes:

- enabling more development in the city centre and greater building heights within walking distance of the city and metropolitan centres and rapid transit stops.
- enabling more intensive development in and around neighbourhood, local and town centres.
- implementing qualifying matters that reduce the required height and density of development where there is a feature or value that should be protected or avoided.

The Auckland Council Planning, Environment and Parks Committee gave direction that all policy settings should be reconsidered. This policy review includes the operative policy direction in the AUP. While this review is underway, recovery, including management retreat and volunteer buy-outs, is also happening.

Directorates within Auckland Council are undertaking shoreline adaptation plans to manage the long-term risk to Auckland Council land and assets, and are also working to reduce Auckland Council organisational and regional carbon emissions, among numerous other climate-related workstreams, that progress the implementation of Te Tāruke-ā-Tāwhiri: Auckland's Climate Plan. The case studies undertaken here may help support Auckland Council in this work and provide an exemplar for other Territorial Authorities seeking to develop an evidence base to inform their policy settings and long-term direction. RiskScape™ also provides the ability to be iterative; if new data or policy settings need to be considered, RiskScape™ can be adjusted to provide risk assessments based on these, which is hugely valuable to councils working through a variety of options.

A1.1 Risk-Based Land-Use Planning

Saunders and Beban (2012) and Saunders and Kilvington (2016) put forward an evolution in land-use planning that incorporates risk into land-use-planning decisions. The risk-based planning framework provides a guide to local government planners through the challenges of this approach, including assessment, engagement and communication strategies. Risk-based planning is becoming common practice in RMA plans. The case studies undertaken here are examples of evidence that can be utilised to inform decision-making within a risk-based framework.

APPENDIX 2 NATURAL HAZARD RISK MODELS

Natural hazard risk models aim to quantify the impact of natural hazards using computer simulations of the hazard itself and the resulting impact on communities. The origin of natural hazard risk models is primarily from the insurance sector, where they are called 'catastrophe loss models' and are used to quantify damage to buildings and infrastructure in an event. This then informs pricing throughout the insurance sector (Kleindorfer et al. 2005; Mitchell-Wallace et al. 2017). However, the majority of these computational models and underlying data and methods are proprietary and are therefore restricted in use through expensive licensing. They are also focused on financial losses and so are less suited for other impacts, such as estimating casualties or down-time of buildings and infrastructure.

In the past 20 years, several 'open' natural hazard impact models with broader applications have been developed. These multi-hazard impact models simulate impacts to a range of exposures, including buildings, infrastructure and people, and aim to estimate impacts across a number of impact types across the '4 Ds': damage, down-time, dollars and deaths. One such example is HAZUS, which is a multi-hazard risk assessment software tool authored by the United States of America's Federal Emergency Management Agency (FEMA) for the mitigation and estimation of loss to buildings, critical facilities, infrastructure networks and effects on population due to a range of different types of hazards, such as earthquakes, hurricanes and floods (FEMA 2020). In Aotearoa New Zealand, the multi-hazard impact tool RiskScape™ was developed by researchers for a range of applications, such as disaster-scenario planning, land-use planning, infrastructure management and insurance (Paulik et al. 2022).

Natural hazard impact models have a common framework (Figure A2.1). Hazard models define the hazard event and its geospatial distribution and intensity. Asset or exposure models are geospatial representations of the community (e.g. buildings, people, infrastructure). This includes their location and attributes of relevance to their vulnerability (e.g. building construction type, etc.). Fragility models are functions that estimate the probability of damage given the hazard intensity for given exposure types. Consequence functions (e.g. casualty function in Figure A2.1) then translate this into impact (e.g. casualties, repair cost, loss of functionality, repair time).

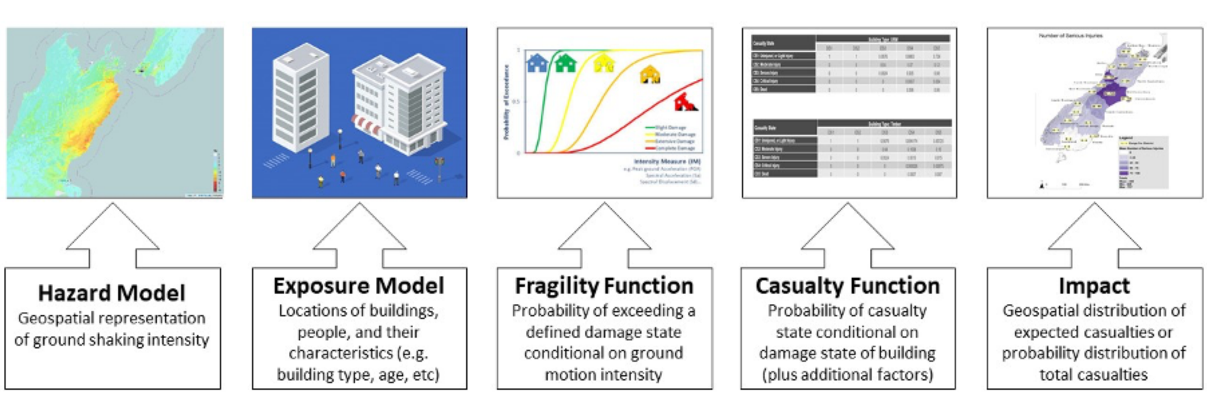

Figure A2.1 Simplified framework of risk models, such as RiskScape™, for earthquake casualties.

A2.1 Previous Work on Risk-Based Land-Use Planning with Natural Hazard Risk Models

RiskScape™[9] is an open-source spatial data processing application used for multi-hazard risk analysis. RiskScape™ is highly customisable, allowing modellers to tailor risk analysis to suit the problem domain and input data being modelled. To use a risk-based approach to natural hazards management, that risk needs to be understood through risk assessments to quantify and inform decision-making. To optimise the usability of RiskScape™, outputs of the policy context in which decision-making will occur needs to be understood. As part of the engagement process for this study, a literature review was undertaken of the ways in which RiskScape™ has been used to inform land-use policy settings and decision-making, as well as comparing that with other tools that support risk-based decision-making. The literature review is contained in Appendix 4 and summarised in Table A2.1.

9 https://riskscape.org.nz/

Table A2.1 A summary of the literature review for previous studies.

User	Parameters	Outputs	Current Status
Queenstown Lakes District Council (2021)	Initial hazards modelled debris flow, rockfall, flooding and liquefaction. This was refined to rockfall and debris-flow risk to life and property. Policy interventions included uncontrolled, managed and reduced development, as well as up-zoning and a baseline.	Risk assessments, engineering risk management options and cost-benefit analysis on property values and socio-economic factors. The modelling outputs showed that levels of risk varied across the area from very high to very low. A risk metric was developed that could be used to manage risk to a tolerable level in the District Plan. Emergency management guidance was provided to manage the residual risk from the land-use policy intervention options (Woods et al. 2021).	In June 2022, approval for further work on the preferred adaptation response option was granted by Council. This package includes physical engineering and land-use policy options to ensure that risk does not increase in tolerable areas, to enable development in areas with low risk assessments subject to further work and to reduce risk in areas with intolerable risk after first resolving funding and compensation mechanisms. Planning analysis is ongoing. The risk to life from debris flow and rock fall in parts of this area are determined to be 'intolerable'.
Hutt City Council (2015)	Tsunami inundation and exposure with vulnerability to inform potential loss of life, injury and building damage.	A limitation of the study was the coarseness of the inundation modelling, which meant that the RiskScape™ assessment was not optimised to understand potential loss of life and property damage. However, quantification of large assets and total number of buildings was possible.	While the finer detail is not available, the outputs do contribute to hazard management strategies by raising awareness of the general level of exposure from tsunami, as well as possible consequences. Further, that expanding the study may aid assessment of risk and planning of locations of critical infrastructure (Lane et al. 2015).
Buller District Council and West Coast Regional Council (2015)	Flood hazard in Westport, adaptation options and climate-change scenarios.	Outputs from possible interventions, including modification of river hydraulics by providing flood plains in the upper catchment, as well as improvements to the capacity and efficiency of channels. Also: containment of flood water by hard engineering of stopbanks, dams and rock walls. Building Act 2004 and RMA interventions, such as finished floor heights and control of new development and infrastructure.	Further flood events have occurred, with ongoing modelling and consideration of adaptation options. Following the July 2021 flood, a business case for future co-investment in protection of Westport was requested and reviewed by Central Government. $22 million funding has recently been announced in response to a $56 million request. There are governance and investment conditions attached to these funds. Further investment by the community, as well as funding of maintenance, requires further public consultation. Currently proposed District Plan provisions require residential finished floor heights to be 500 mm above a 1% AEP event.

APPENDIX 3 RISKSCAPE™ MODELLING FRAMEWORK AND TECHNICAL DETAIL

RiskScape™ is an open-source risk modelling software created by GNS Science, NIWA and Toka Tū Ake EQC, with development and implementation largely undertaken by Catalyst IT Ltd. RiskScape™ allows users to deploy deterministic, stochastic or probabilistic single- or multi-hazard risk assessment models. RiskScape™ incorporates a software engine (Figure A3.1), command line interface and the RiskScape™ Platform, which offers access to run RiskScape™ models and view results through a web-based interface.

The RiskScape™ modelling engine is flexible for single- or multi-hazard risk analysis. It implements user-defined risk quantification workflows as ‘model pipelines’ to analyse hazard, exposure and vulnerability data across different spatio-temporal domains using geoprocessing and spatial sampling. Multiple hazard types, with different metrics, intensities and temporal occurrences, can be geometrically processed and sampled to create coverage data of simultaneous or sequenced multi-hazard events at object-exposure locations. Compounding multi-hazard event impacts are then determined for object exposures using scripted conditional or nested statements that apply vulnerability functions in a logical sequence of temporal hazard and impact occurrence (Paulik et al. 2022). RiskScape™ allows a consistent framework for risk assessment to be developed and re-produced in other projects.

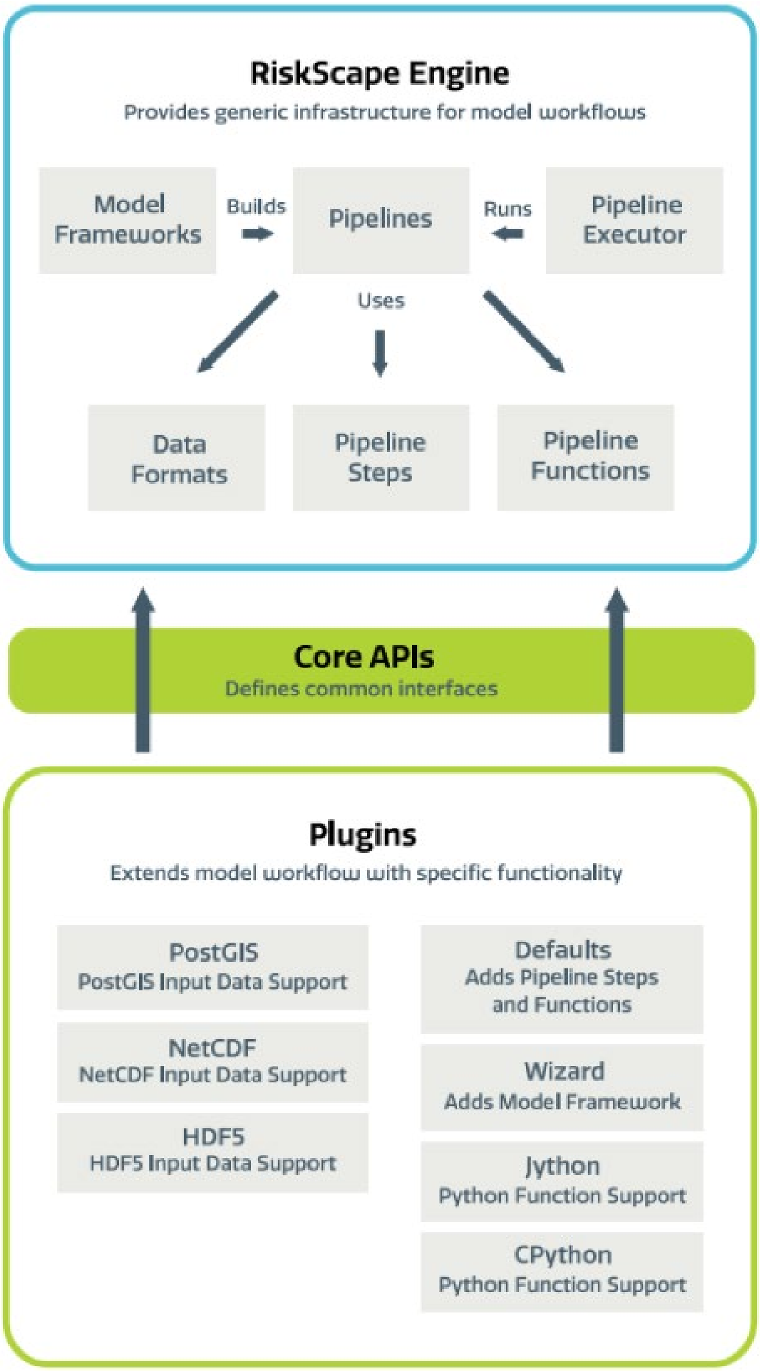

Figure A3.1 A simplified conceptual diagram of the core RiskScape™ engine components and plug-ins (Paulik et al. 2022).

RiskScape™ was created to help simplify decision-making related to natural hazard risk. The software is modular and can be extended to meet the needs of different types of users globally. RiskScape™ is summarised below, followed by a description of pipeline operations and data formats.

RiskScape™ is open-source, allowing transparency in the modelling workflows and calculations, providing more confidence to end users of the steps undertaken in any analysis. This differs from ‘black box’-style software products, where the models and calculations are not available to end users.

The sections below summarise the RiskScape™ engine and RiskScape™ pipelines concepts. For further details, see Paulik et al. (2022).

A3.1 RiskScape™ Engine

RiskScape™ implements a modular design (Figure A3.2), where risk is a function of hazard, vulnerability and exposure. Consequences (e.g. loss or damage) are calculated either for individual events (deterministic or stochastic) or probabilistically, with workflow documented in a 'model pipeline'. Each event may either be represented by a single hazard or multiple hazards, i.e. compounding or cascading.

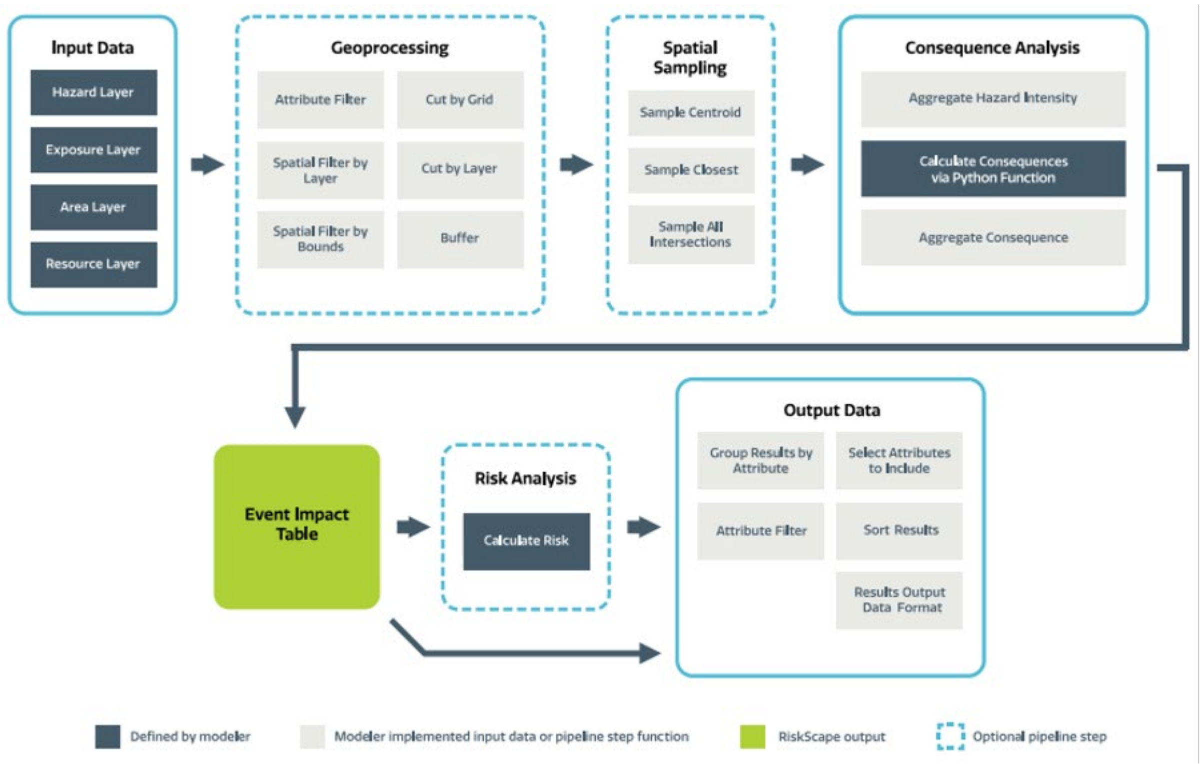

Figure A3.2 RiskScape™ model pipeline schematic representation of pipeline steps and functions (Paulik et al. 2022).

A3.2 RiskScape™ Pipelines

Pipelines are code that can be utilised within RiskScape™ to allow the user to create a specific risk-modelling workflow. Pipelines are implemented as data selection steps, where data are imported into RiskScape™, transformed, processed and exported in standard spatial and non-spatial data formats (e.g. *.csv*, *.shp*, *.gdb*). Pipeline selection steps include geoprocessing (spatial matching of hazard and exposure), consequence analysis (vulnerability or fragility functions applied to calculate consequences for individual events), risk analysis (which then incorporates event probability) and aggregation (allowing export at various spatial resolutions). Data is passed between each pipeline step as 'tuples', each representing a single data record or attribute list (Paulik et al. 2022).

Pipelines are supported by various text files, which define data and functions. Pipelines for each of the case studies are available at: https://github.com/GNS-Science/riskscape/land-use-planning-case-studies/

For more detailed information, readers are referred to Thomas et al. (2020) and RiskScape™ documentation found at www.riskscape.org.nz.

APPENDIX 4 LITERATURE REVIEW

This literature review considers the way in which RiskScape™ has been used to inform land-use policy setting and decision-making, as well as other tools that support risk-based decision-making. To inform this review, the published case studies using RiskScape™ have been reviewed to understand how they have informed land-use policy direction and decision-making. The two principal cases are debris flow / rockfall with the Queenstown Lakes District Council (QLDC) and coastal tsunami inundation with Hutt City Council (HCC). Other cases where these specific hazards have been managed through land-use planning and decision-making have been included to allow comparison with other tools. Also, a multi-hazard assessment and policy-direction change is included to allow comparison with the current case-study work as a multi-hazard approach. A case, led by NIWA, focuses on fluvial flooding risks in Westport and highlights the ways in which RiskScape™ can inform long-term direction without necessarily being part of immediate decision-making. This literature review is not a comprehensive study of all risk modelling tools used for land-use policy setting and decision-making. It is focused on the cases developed and comparison studies to inform the engagement process for this case study.

Commencing 2019, QLDC, GNS Science and Beca have been collectively working to manage natural hazard risk for Brewery Creek and Reavers Lane. Initial assessments and community engagement to understand risk tolerance were undertaken, with endorsement by Council to progress more detailed work. Risk from debris flow, rockfall, flooding and liquefaction were modelled.

Further risk assessments were undertaken, including engineering risk-management options, cost-benefit analysis on property values and socio-economic factors. Rockfall and debris flow hazards were the focus, as they present the greatest risk to life and property. Policy interventions, including uncontrolled, managed and reduced development, as well as up-zoning, and a baseline were modelled to understand the risk implications of those interventions. The modelling outputs showed that levels of risk varied across the area from very high to very low. A risk metric was also developed that could be used to manage risk to a tolerable level in the District Plan. Emergency management guidance was provided to manage the residual risk from the land-use policy intervention options (Woods et al. 2021). These assessments were provided to Council in September 2021 with a request to commence community consultation on a preferred option. In June 2022, approval for further work on the preferred option was granted by Council.

Planning analysis is ongoing. The risk to life from debris flow and rock fall in parts of this area are determined to be ‘intolerable’. This determination comes from an exceedance of Australian Geomechanics Society (AGS) guidelines, the Proposed Otago Regional Policy Statement 2021 (RPS) and the Natural Hazards chapter of the Proposed District Plan (which requires risk to be managed to tolerable levels). The following diagram, from the Beca (2020) report, illustrates various activities, including the risk to life in the case-study area. A table expressing risk to life is also included (Table A4.1).

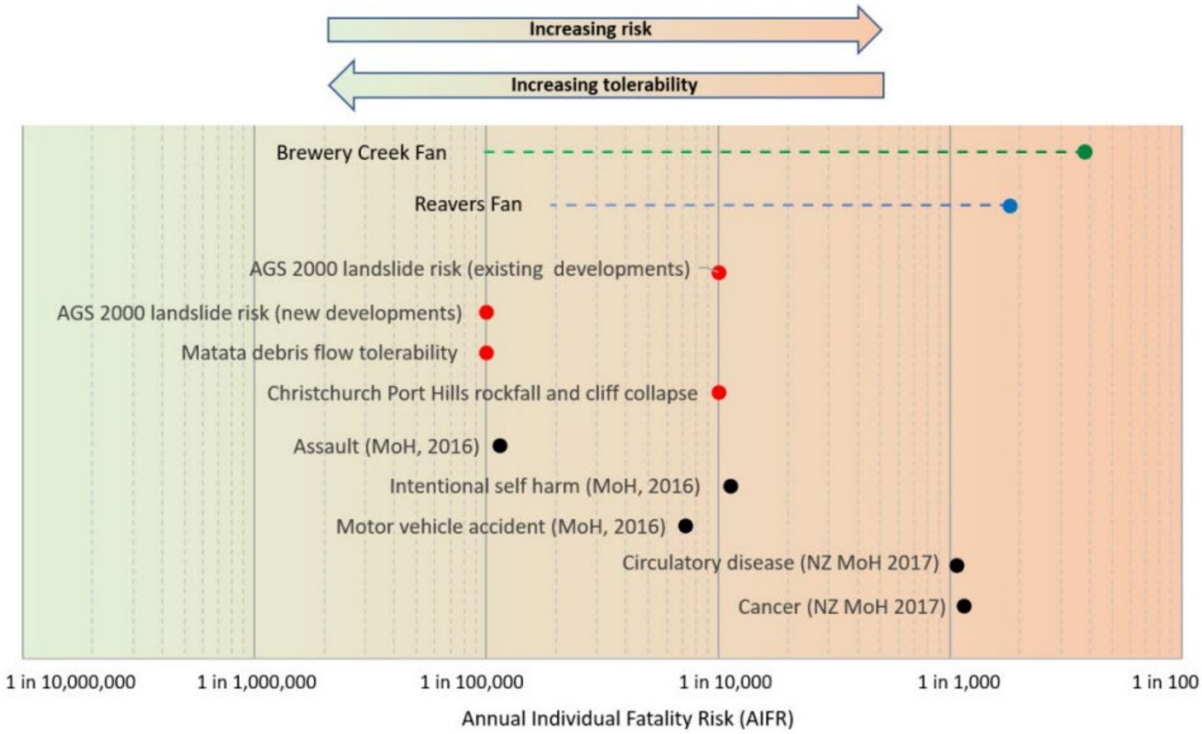

Figure A4.1 An illustration of the range of risk levels present across Brewery Creek and Reavers Lane, including a comparison of common risks and tolerability guidance (Beca 2020).

Table A4.1 Ways of expressing risk probability (Beca 2020).

Probability 1 in … (per year)	Is the same as (per year)	Is the same as (per year)	Is the same as (per year)	Is the same as (over lifetime)
1000	10^{-3}	0.001	0.1%	8%
10,000	10^{-4}	0.0001	0.01%	0.8%
100,000	10^{-5}	0.00001	0.001%	0.08%
1,000,000	10^{-6}	0.000001	0.0001%	0.008%

Currently, an RMA plan change to implement the land-use options has not been notified to the operative District Plan. The early and ongoing work will inform any proposed plan change and can be expected to form part of the RMA s32 analysis that would need to be provided to inform that change. While a plan change has not been notified, it cannot be directly considered in decision-making; however, under a subdivision consent, s106 and considerations of natural hazards, this work and resultant reports could be considered under a natural hazard assessment and so may inform decision-making. It may be that the QLDC Civil Defence Emergency Management team use the report for decisions in regard to evacuation planning.

The Whakatāne District Plan, Plan Change 1, provides a comparison to the ongoing QLDC management. The genesis of this case was a 2005 debris flow that inundated the coastal settlement of Matatā. Tonkin & Taylor were engaged to undertake a landslide risk assessment. The assessments were undertaken in accordance with AGS (2007). A table produced by Tonkin & Taylor (2013) follows, showing the spectrum of risk in the low, medium and high areas (Table A4.2). The probability of loss of life in the high-landside-hazard zone is at least as likely as the QLDC case. It is noted that the QLDC case has a spectrum of risk, the low end of which is the high end of the Matatā case. A risk of death of 1 in 100,000 per year is an unacceptable risk for residential activities.

Table A4.2 Annual loss of life risk for landslides for moderate to high hazard zones (from Tonkin & Taylor [2013]).

Location	Landslide Hazard Zone	Risk Factors						$R_{(LOL)}$	AGS (2007) Classification
		$P_{(H)}$	$P_{(S:H-1)}$	$P_{(S:H-2)}$	$P_{(T:S-1)}$	$P_{(T:S-2)}$	$V_{(D:T)}$		
West of Awatarariki Stream	High	4.6×10^{-1}	-	-	-	-	-	N/A	-
	Moderate	4.6×10^{-1}	-	-	-	-	-	N/A	-
Awatarariki Stream to Division Street	High	1.6×10^{-1}	9.0×10^{-2}	$1.0 \times 10^{0\,e}$	7.5×10^{-1}	2.5×10^{-1}	7.5×10^{-1}	2.0×10^{-3}	Very high
	Moderate	1.6×10^{-1}	3.0×10^{-1}	5.0×10^{-2i}	7.5×10^{-1}	2.5×10^{-1}	7.5×10^{-1}	3.4×10^{-4}	High
South of Division Street	Moderate	1.2×10^{-1}	1.7×10^{-1}	5.0×10^{-2i}	7.5×10^{-1}	2.5×10^{-1}	7.5×10^{-1}	1.4×10^{-4}	High

Boffa Miskell (Batchelar 2018) were engaged to develop ways of managing that risk. Engineering options were explored for several years to try to ascertain a way in which to capture a future debris flow before it inundated the settlement. In 2012, it was accepted by Whakatāne District Council (WDC) that this was not feasible. Early warning systems were also investigated. These were also found to be an inappropriate way of managing the risk (Davies 2020).

A combined plan change was lodged by WDC to amend its District Plan (WDC [2023]) and, through Proposed Plan Change 17, insert provisions for debris-flow risk management on the Awatarariki fanhead at Matatā into the Natural Hazards chapter of the Bay of Plenty Regional Natural Resources Plan (BOPRC c2023). The change was requested to manage the risk to people’s safety by creating policies and rules to end residential activity on high-risk properties within the fanhead and extinguish existing use rights on those properties. The combined plan change became operative in March 2021. One property right to reside was extended to March 2022. This case highlights the substantial amount of time – 17 years, as well as cost and collaboration required to move from initial assessments to a change in an RMA plan being operative.

A further landslide-specific example of risk assessment tools informing land-use planning and decision-making is the Port Hills, Christchurch. Following the Christchurch earthquake sequence, damage was assessed. GNS Science developed a relative hazard exposure matrix to support Christchurch City Council (CCC) to identify priority areas for future investigations, as well as potential ways to manage them. The matrix is based on the risk management framework found in the Risk Management Guidelines Companion to AS/NZS 4360:2004 (Massey et al. 2013). This assessment identified potential areas in the Port Hills that were at risk from landslide. The risks were given classes: Class I is for areas where landslides could see loss of life, property and damage to critical infrastructure. Class II and Class III also present risk to property and infrastructure but not risk to life.

In 2014, further assessments revealed that some residential properties were at intolerable risk from landslide. These assessments used the same method as the WDC case, the AGS (2007) guidelines for landslide risk management. The intolerable risk is: risk to life from landslide in any one year is equal to or greater than 1 in 10,000. This is an order of magnitude greater than the WDC case and is within the spectrum of the QLDC case. The properties have been purchased to extinguish existing use rights and reduce risk to a tolerable level. These three cases highlight the assessment and modelling tools required to understand the level of risk and the options to manage that risk, such as engineering and civil defence planning. In the WDC and CCC examples, the risk was not able to be managed to a tolerable level through such interventions, which resulted in existing use rights being extinguished.

The QLDC case is still considering options (QLDC 2022), and, while it may be used in some decision-making and land-use planning, it has not yet gone through the RMA process.

RiskScape™ was used in the Wellington region to assess risk from tsunami inundation overlaid with vulnerability to understand potential loss of life/injury and building damage. The study was heavily reliant on the inundation and exposure model outputs. A limitation of the study was the coarseness of the inundation modelling, which meant that the RiskScape™ assessment was not optimised to understand potential loss of life and property damage. However, quantification of large assets and total number of buildings was possible. The study notes that, while finer detail is not available, the outputs do contribute to hazard management strategies by raising awareness of the general level of exposure from tsunami and possible consequences. Further, that expanding the study may aid assessment of risk and planning of locations of critical infrastructure (Lane et al. 2015).

The National Policy Statement for Urban Development (NPS-UD) has been gazetted, which requires the up-zoning of land where appropriate. HCC, in their preparation of Plan Change 56 (PC56), have used tsunami risk as a ‘qualifying matter’. Qualifying matters are RMA s6 matters that can be used to constrain intensification. HCC have proposed to exclude ‘high tsunami risk’ areas from intensification. This exclusion is not directly based on the RiskScape™ study, instead using probabilistic tsunami hazard maps (Burbidge et al. 2021). However, as the QLDC, CCC and WDC cases show, such change while considering land-use planning and decision-making takes years, and the raising of awareness through the RiskScape™ case study has led to further work and management approaches (Gerard 2023, pers. comm.).

Returning to Christchurch, a tsunami risk framework was developed through a collaborative case study between practitioners and researchers to understand tsunami impact on critical infrastructure, in particular, roading and electricity. The study is focused on critical infrastructure, as it is paramount to societal functioning, and it is therefore prudent to include infrastructure vulnerability in risk models as a way to inform risk reduction and response planning. The impacts to society from lack of essential services can include community isolation, displacement, economic loss and psychological impacts (Williams et al. 2022).

Throughout this study, consultation was undertaken. The ongoing collaboration refined the impact model, which informed the impact assessment, and in turn improved the likelihood that the research outputs were taken up and implemented. Environment Canterbury have been undertaking coastal hazard management consultation. Tsunami risk is part of that overall picture. CCC have recently notified their plan change to give effect to the NPS-UD. A similar approach to HCC has been taken with using tsunami risk as a qualifying matter. The outputs from the RiskScape™ framework are not being used in either of these management approaches; however, they have contributed to the general understanding and awareness of this hazard in the region (Jack 2023, pers. comm.).

The approach taken in the QLDC, WDC and CCC landslide examples is different to that taken for tsunami. The intent of the tsunami cases was more focused on infrastructure, whereas, for land instability, the risk to life is much higher and management processes are different. There is potential to plan and evacuate for tsunami; for land instability, particularly in the areas, studied engineering solutions were not found to be feasible. This remains to be seen for QLDC, but materials so far suggest that this may not be possible.

In 2012, NIWA RiskScape™ co-developers modelled flood hazard with options for adaptation, including climate-change scenarios workshopped with Buller District Council (BDC) and West Coast Regional Council (WCRC) representatives. The adaptation methods included engineering, such as modification of hydraulics by providing flood plains in the upper catchment, and improvements to the capacity and efficiency of channels. There was also containment of flood water by hard engineering of stopbacks, dams and rockwalls. Building Act 2004 and RMA interventions were also tabled, such as increasing finished floor heights and control of new development and infrastructure (Keenan and Oldfield 2012).

Since that time, Westport has experienced numerous severe weather events – Cyclone Ita, ex-Cyclone Fehi, the July 2021 floods and the February 2022 floods. There have also been numerous floods historically. The pā was moved twice due to flooding and was situated on the true left of the river, not the true right, the town's current location (Tumahai 2021, pers. comm.). WCRC consulted on flood protection options for Westport in its 2021–2031 Long-Term Plan (WCRC 2021). In July 2021, rainfall resulted in a peak flow of 8900 m^3 per second. 2000 people were evacuated from 826 properties. 563 houses were 'yellow stickered' and 71 'red stickered'; this is 23% of the town's residential stock.

Minister Mahuta, the then Minister for Local Government, invited a business case for joint investment in Westport's future. A case was prepared by BDC, Te Runanga o Ngāti Waewae and WCRC (Cleine et al. 2022). Land River Sea Consulting (LRS) developed flood mitigation options for Westport (Gardner 2022), Greymouth, Hokitika and Franz Josef. These models, not the NIWA RiskScape™ 2012 outputs, were used for the business case. The 2017 Westport model has been refined and calibrated following ex-Cyclone Fehi. The options put forward for Westport protection had been further refined against the July 2021 flood. The hydraulic modelling outputs show both depth and velocity for selected climate-change scenarios, as well as breach scenarios for existing and proposed protection and a 'banks down' scenario. These models also have the benefit of recent LiDAR, which improves accuracy due to ground levels being more accurately known. The outputs of the models were then considered by a Technical Advisory Group and a preferred option ($56M) put forward in the business case to central government. In May 2023, it was announced that central Government will provide $22.6M in funding for hard protection and raising floor levels. Community consultation will need to be undertaken to decide exactly how those funds will be spent, how short falls will be met and how ongoing maintenance will be funded.

Concurrently, a combined district plan for the West Coast, Te Tai o Poutini Plan, has been developed. The draft plan required residential finished floor heights to be 500 mm above a 1% AEP event. Overlays of 'flood severe' and 'flood susceptibility' were applied to the township. These overlays were linked to the LRS outputs, and Australian Disaster Resilience Flood Management Categories were used, risk categories 5 and 6 (more than 2 m of water or moving at more than 2 m/s) being marked as 'flood severe' and the remaining using the 'flood susceptibility' overlay. Strong public feedback was received that this was inappropriate, as hard engineering structures will resolve this.[10] The notified proposed plan was amended to incorporate this feedback, showing the area as 'Westport Hazard Overlay', with a sunset clause. The Westport Hazard Overlay also incorporates the coastal inundation and erosion areas. Hearings are likely to be scheduled for later this year. This case highlights the progression from initial assessments to further assessments, ongoing engagement and collaboration.

NIWA have also undertaken another flood-specific case study. The case was in collaboration with the Aotearoa New Zealand Climate Change Research Institute at Victoria University of Wellington. The purpose of the case was to understand how vulnerability to flood risk increased with climate change. The report outlines the methodologies and current approach with property

10 https://ttpp.nz/wp-content/uploads/2022/03/TTPP-Agenda-29-March-2022.pdf

infrastructure and life parameters. It does not appear that the report was intended to directly influence specific decision-making; moreover, it was to support the development of RiskScape™ as a decision-making tool (Reese and Ramsey 2010).

Franz Josef, West Coast, has been the subject of extensive natural hazard and risk assessments, as well as cost-benefit analysis. This area serves as a comparison with the multi-hazard approach being undertaken with Auckland Council in this current case study. Franz Josef sits astride the Alpine Fault and next to the highly dynamic Waiho River. These hazards are well known to both the local and scientific communities. There is also potential for mass movement from range front collapse, although debate continues as to the degree of risk. While many assessments and reports have been produced, McSaveney and Davies (1998) produced a consolidated assessment for WCRC with hazard-management options. Further work was undertaken, and, in 2012, Westland District Council notified a plan change to manage flooding and fault-rupture risk. This plan change progressed through the RMA Schedule 1 with hearings in 2015, progressing to appeals. However, at the first meeting of a newly elected Council, the plan change was withdrawn. In 2017, Tonkin & Taylor provided an options assessment and cost-benefit analysis for Franz Josef. The outcome of that work was that the best option was to re-locate the township. As above, the combined District Plan for the West Coast has now been proposed. This plan puts forward refined fault avoidance management as further work, as imaging has made the fault location more accurate, as well as flooding provisions. Concurrent to this, Franz Josef received infrastructure funding from Central Government to undertake further protection works from the Waiho River. These works are currently going through the resource consent process. This area-specific overview highlights the challenges of the RMA process and the length of time it can take to navigate that process. Community consultation was undertaken with both RMA proposed changes. It is not clear as to the amount of consultation undertaken in regard to the various science and consultancy reports. It has been 25 years since the McSaveney and Davies (1998) hazard assessment.

RiskScape™ has been used to undertake case studies considering risk from landslide, tsunami and flooding. For those hazards, studies not using RiskScape™ have also been considered to compare and contrast how assessment tools can be used. To date, RiskScape™ has not directly influenced RMA land-use planning and decision-making but has influenced future work that has resulted in change. It may be that the QLDC work does directly result in a plan change. The case study being undertaken with Auckland Council seeks to further early work by undertaking comprehensive consultation with key stakeholders. While this has happened in other case studies, the Auckland Council stakeholders have future work programmes that may enable them to implement the study outcomes with shorter timeframes than the other examples. While the methodology used for the assessments both within RiskScape™ and using other methods are not part of the scope of this literature review, it is worth noting that the continual evolution and refinement is a strength of RiskScape™.

APPENDIX 5 ADAPTATION CONTEXT: OREWA

The impact of climate change and its inter-relationship with land-use planning has strong relevance in this case study area. The ongoing and increasing exposure to coastal erosion and inundation, and how to respond to this, has been a decadal process for Orewa. Prior to the amalgamation of Auckland's districts into a 'supercity' in 2010, the previous local council attempted to put in place protection works along Ōrewa Beach. This resulted in long-term movement of sand from the estuary to replenish the beach. Each year, 25,000 m^3 of sand from the southern part of Ōrewa Beach is extracted, with 10,000 m^3 used to replenish the beach in front of Ōrewa Reserve (to the south of the subject area). The balance of 15,000 m^3 is available for replenishment of other parts of the beach. Following the creation of the supercity, and several large storm events that accelerated erosion, it was recognised by Council that this method would not be sufficient to maintain the publicly owned strip between the beach and private properties. There was also a desire by Council to provide a public-access track along that strip to recognise the needs of the Orewa population and the recreation value of the area generally.

Resource consent was applied for by Auckland Council's Parks Team, which was declined by independent commissioners due to effects on coastal processes, public access, natural character and amenity of the area. The decision was clear that hard-protection structures should only be a last resort. The decision was appealed in the Environment Court in 2017, firstly as to whether the Council could appeal itself (it could) and secondly as to the decision itself. The proposal was amended through the court process, and the consent was issued in 2020. The Court process had to weigh the considerations of public access – would the proposal improve or hinder this, over what timeframe – as well as similarly for natural hazards – what effect would the proposal have on response over what timeframe. A substantial factor in the decision was that the revised design is no longer in the Coastal Marine Area. This area, due to its sensitivity, has highly restrictive provisions both at a national level through the New Zealand Coastal Policy Statement and through the Regional Coastal Plan. Removing the design from this area meant that these objectives and policies no longer needed to be considered and that consent was not required. Benefits from the proposal referenced are protection of the esplanade reserve from risks of natural hazards; securing of public access; enhancement of recreational and other amenity values, including coastal vegetation and trees; and avoidance or mitigation of adverse effects on coastal processes and landscape and natural character values.[11] This consenting history provides policy context and an insight into the community aspirations for adaptation.

11 Environment Court cases: Auckland Council vs Auckland Council [2020] NZEnvC 70 (27 May 2020); Auckland Councils vs Auckland Council [2018] NZEnvC 56 (2 May 2018).

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