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THE 2023 LANDSLIDES AND ENGINEERING GEOLOGICAL RESPONSE IN AUCKLAND, NEW ZEALAND

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Abstract

Auckland is the largest urban area of New Zealand's North Island with a population of ~1.7M. Auckland has a sub-tropical climate, with warm and humid summers which can be associated with intense rainfall. January 2023 was Auckland's wettest month since records began. The heaviest rainfall produced widespread flooding across Auckland on Friday 27 January described as at least a 1-in-200-year event. Two weeks later Cyclone Gabrielle hit Auckland. West Auckland recorded 248 mm of rain. Tragically these events resulted in six deaths in Auckland, three of which occurred when landslides hit buildings. Two volunteer firefighters lost their lives while undertaking search and rescue operations, and tens of thousands of landslides were triggered. This paper describes the storm events, the landslides they triggered, and the emergency response work undertaken by engineering geologists and geotechnical engineers.

Key words

landslides, Auckland, New Zealand, risk, emergency response

1 Introduction

Auckland is the largest city in New Zealand (Fig 1). Home to around a third of the 5 million New Zealanders, it contributes almost 40 per cent of the nation's gross domestic product. "Tāmaki Makaurau", the Māori name for Auckland, means Tāmaki desired by many. This name reflects the abundance of natural resources, strategic vantage points, portage routes, and food-gathering places which first attracted Māori, and then other settlers. Set between the Tasman Sea and the Pacific Ocean, Auckland has 3,200 km of coastline, many hills and rivers, and numerous sandy beaches backed by volcanoes of the Auckland Volcanic Field. Auckland has a sub-tropical climate, with warm and humid summers which can be associated with intense rainfall.

The geology of Auckland is relatively young. Much of the area is underlain by relatively poorly cemented Miocene sandstones and mudstones, and volcanics of the same age or younger (Fig 2). These weather relatively rapidly to sensitive residual clays and silts. In addition, colluvium deposits from reworking of residual soils and former landslides exist on slopes, while late Pleistocene and Holocene fluvial deposits occupy valley floors (Edbrooke et al. 2003).

Landslides are one of New Zealand's most significant natural hazards. Since 1760 there have been at least 1,500 deaths from landslides in New Zealand. More fatalities have occurred from landslides than from earthquakes (501), volcanic activity (179) and tsunami (1) combined over the last 160 years (de Vilder et al, 2024). A lower estimate of the national annual cost associated with landslides is NZ $250–$300 M/year (Rosser et al, 2017).

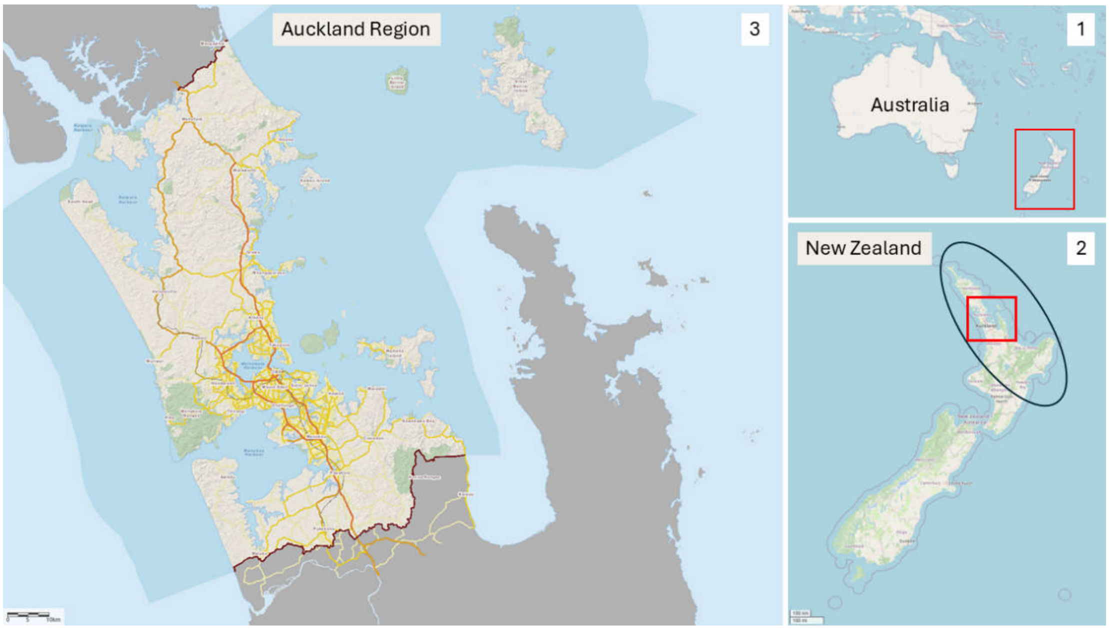

Figure 1. Location. 1.1 Shows New Zealand (red box) relative to Australasia. 1.2 Shows Auckland (red box) relative to New Zealand, with Cyclone Gabrielle affected areas in blue oval. 1.3 Shows Auckland Region with surrounding areas in grey. The damage encompased the full region (OpenStreetMap / Auckland Council).

Landslides across Auckland generally are of shallow depth (<10 m), commonly forming in the weathered soil mantle or along the soil/rock interface. Typically in this region, surface materials become saturated, decreasing effective stress and causing failure shallow landslides across more competent underlying bedrock (Palma et al. 2020). Tens of thousands of landslides can occur across a region in a single storm, causing fatalities and damaging property and infrastructure. Such events create particular challenges for disaster response agencies (e.g. Roberts 2023).

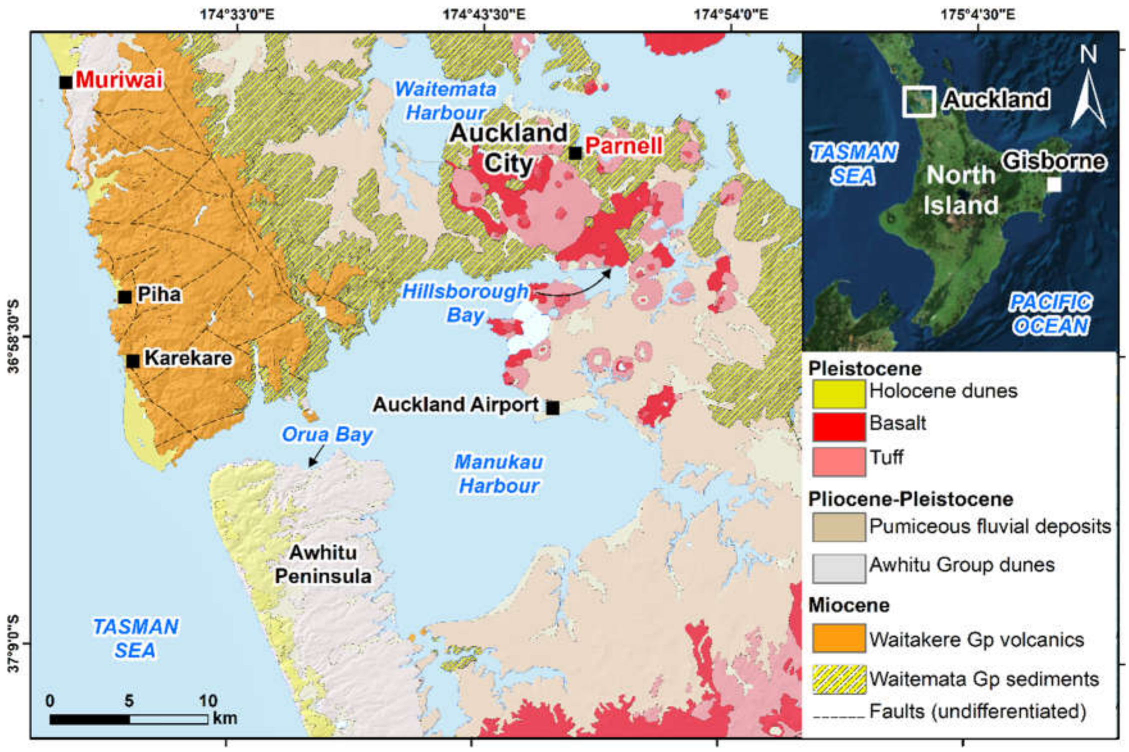

Figure 2. Generalized regional geology of Auckland with locations of fatal landslides in Parnell (January 27, 2023) and Muriwai (February 13, 2023) highlighted in red font.

2 The Auckland Flood and Cyclone Gabrielle

2.1 Meteorological summary

January 2023 was Auckland's wettest month since records began, with 539 mm recoded at a central Auckland rain gauge at Albert Park (Fig 3). The heaviest rainfall produced widespread flooding across Auckland on Friday 27 January, which the National Institute of Water and Atmospheric Research (NIWA) described as at least a 1-in-200-year event. On that day, Auckland's Albert Park recorded 280 mm of rain in under 24 hours and 211 mm in under 6 hours. Central Auckland experienced over 45% of its yearly rainfall in just one month, over 8.5 times the January average (NIWA, 2023).

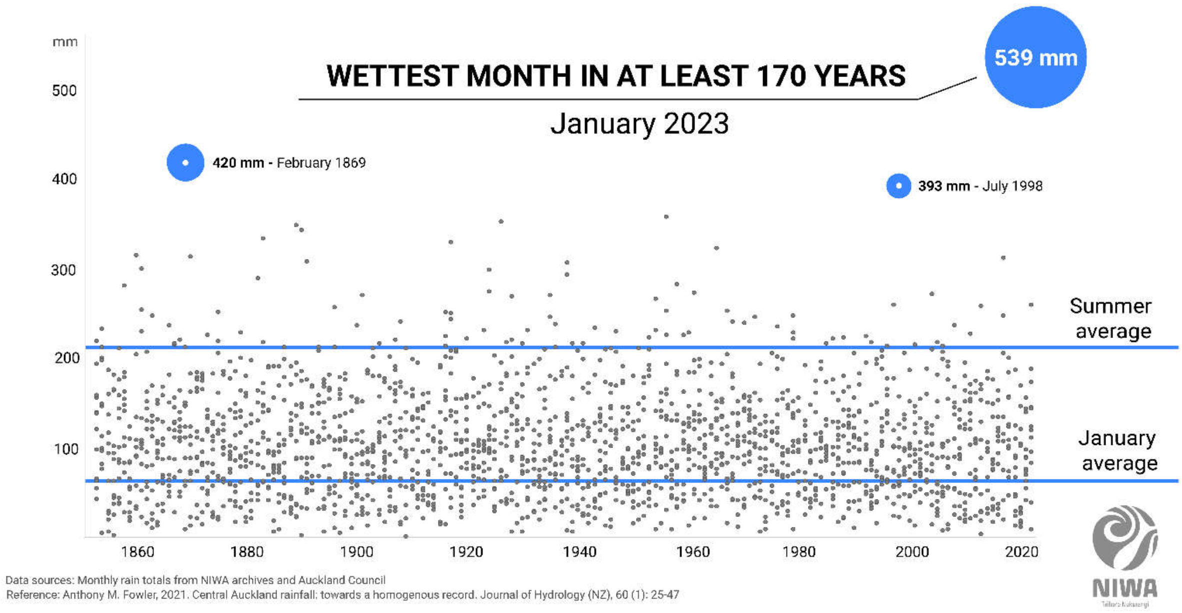

Figure 3. Central Auckland monthly rainfall (1853-2023). NIWA graphic: https://niwa.co.nz/news/auckland-suffers-wettest-month-in-history

The wet month resulted in extremely high groundwater levels. A central Auckland monitoring location at Mt Eden gave the highest groundwater level recorded since the station was installed in 1997, 2.5m above the average winter high level (Auckland Council internal data). New and reactivated springs formed across the central city, causing additional flooding.

Just two weeks later in the early hours of 14 February 2023, a second weather event, Cyclone Gabrielle, hit Auckland. West Auckland recorded 248 mm of rain and winds gusting up to 150 kph (Fig 4). The storm continued south, affecting many other areas along the east coast of the North Island of New Zealand. A National State of Emergency was declared on 14 February, applying to the six regions most impacted by the cyclone: Northland, Auckland, Tairāwhiti, Bay of Plenty, Waikato, Hawke's Bay and Tararua District. This was only the third time a National State of Emergency had been declared.

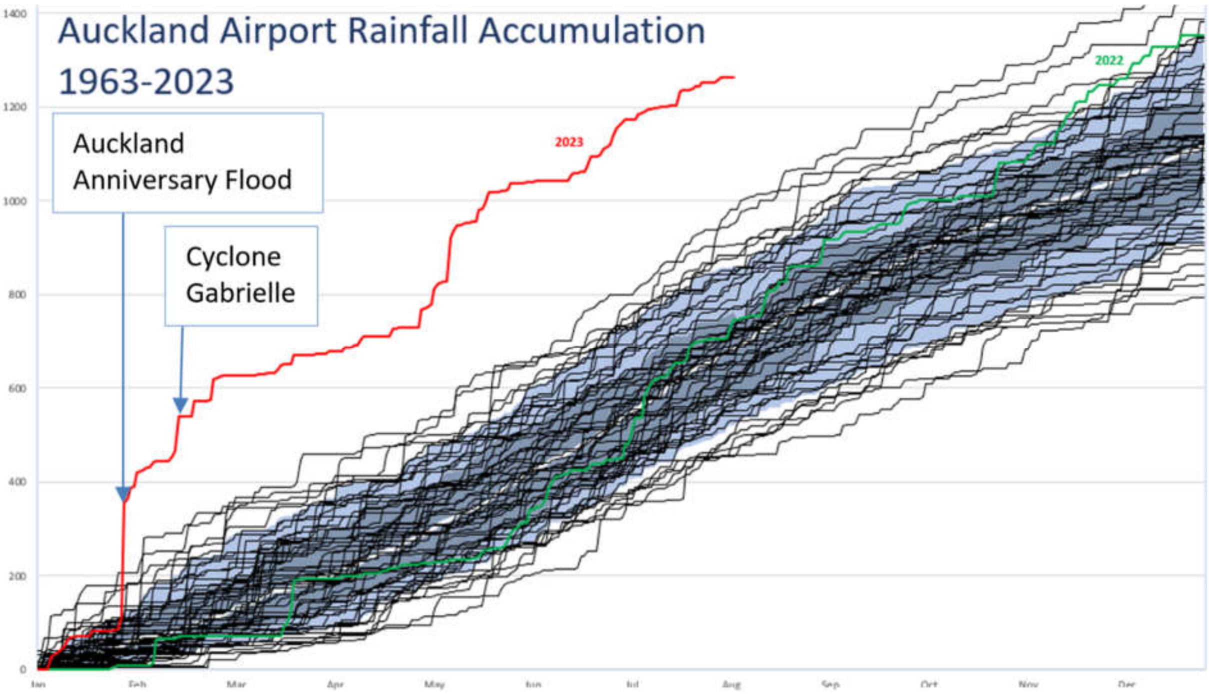

Figure 4. Auckland Airport cumulative annual rainfall. White line is 1991-2020 normal annual rainfall. Green = 2022 rainfall accumulation, dark grey shading shows 25-75th interquartile range, light grey shading shows 10-90th interquartile range. (G Griffiths, MetService, personal communication, Aug 2023)

2.2 Impacts

The intense rainfall on 27 January and 14 February resulted in thousands of landslides, including many on coastal cliffs and populated inland areas (Fig 5). While the impacts of the January storm were generally limited to Auckland, Cyclone Gabrielle also hit other regions in New Zealand. Nationwide over 140,000 landslides triggered by these two events have been mapped. Eleven people lost their lives and nearly 2,000 people were injured during the cyclone (Public Health Communications Centre Aotearoa, 2023). In Auckland the two events caused three fatalities due to landslides. One occurred on 27 January in Parnell when a landslide hit a home, and two volunteer firefighters tragically lost their lives to landslides in Cyclone Gabrielle while rescuing residents in the coastal settlement of Muriwai.

In Auckland most landslides were shallow. Highly mobile flows occurred in Awhitu Group sands where they were commonly triggered by smaller shallow rotational or translational landslides. Similarly mobile flows occurred in Waitemata Group East Coast Bays Formation residual soils where these were on longer steep hills, in one case damaging the North Auckland main trunk line near Wellsford (Fig 6.2). Translational landslides in residual soils and colluvium formed on Waitakere Group Volcanics at Karekare. Around central Auckland, hundreds of landslides occurred on the Waitemata Group East Coast Bays Formation residual soils and weathered rocks, particularly on clifftops around Manukau Harbor and Waitemata Harbour (Fig 6.1). Many houses around the coastal cliffs often have minimal "setback" (<10 m) from cliff edges (Brook and Nicoll, 2024).

Many homes were rendered uninhabitable by the landslides and flooding, with nearly 2,000 families displaced from their homes in Auckland in the immediate aftermath of the storms. Over 6,000 tonnes of waste was generated, creating a significant hazard as much of it was contaminated with sewerage. There were over 1,300 landslides on the roading network in Auckland, and an estimated $2.5 billion in private insurance claims. 8,500 vehicles in Auckland were damaged, mostly by flooding.

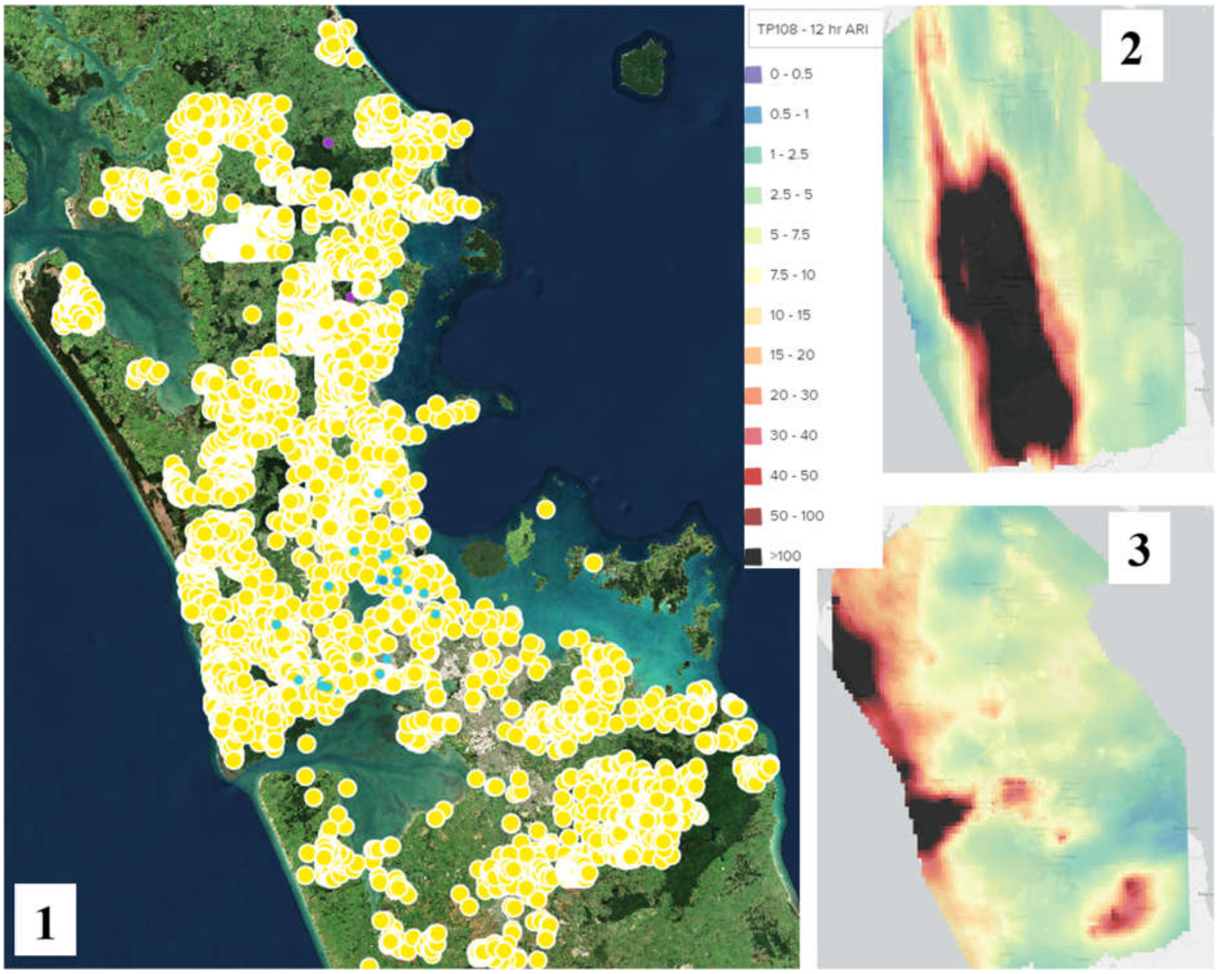

Figure 5. 1) Landslides mapped in the Auckland region after Cyclone Gabrielle and the Auckland Anniversary Floods, showing spatial distribution covering the full region (NZ Landslides Database, extracted 16 May 2024). 2) Rainfall intensity distribution for Auckland Anniversary Flood (12hr ARI maximum between 12:00 on 27 Jan and 12:00 on 28 Jan). 3) Rainfall intensity distribution for Cyclone Gabrielle (12hr ARI maximum between 12:00 on 13 Feb and 12:00 on 14 Feb). Areas with ARI>100 years shown in black.

3 Engineering Geological Response

Engineering geologists and geotechnical engineers (geo-professionals) from the public and private sectors volunteered extensive hours to serve their communities during the emergency response. In general practice in New Zealand the following stages occur, in series or in parallel, during a response:

1. Initial response / Rapid Impact Assessment
2. Infrastructure assessments
3. Rapid Building Assessment
4. Interim Use Evaluation
5. Detailed Damage Evaluation
6. Insurance Assessments
7. Private Remedial Assessments

Further explanation is available in Chapter 11 of the New Zealand Geotechnical Society Slope Stability Guidance Unit 1 (NZGS, 2023). In this event, an additional phase of risk categorisation was added following a mandate from central government to identify which homes were not appropriate for ongoing occupation, and should be bought out by the government (Roberts et al, 2024).

3.1 Initial response and infrastructure assessments

When a local or national state of emergency has been declared, emergency services (including Urban Search and Rescue and Civil Defence Emergency Management) complete initial assessments on the ground and from the air, and collate information on overall impacts. Priority was given to homes where there may be casualties or vulnerable residents, then to life-critical infrastructure. These first responders were exposed to natural hazards such as landslides. To manage this risk, geo-professionals provided on-call support, acting as spotters and proving advice for any works around and near landslides.

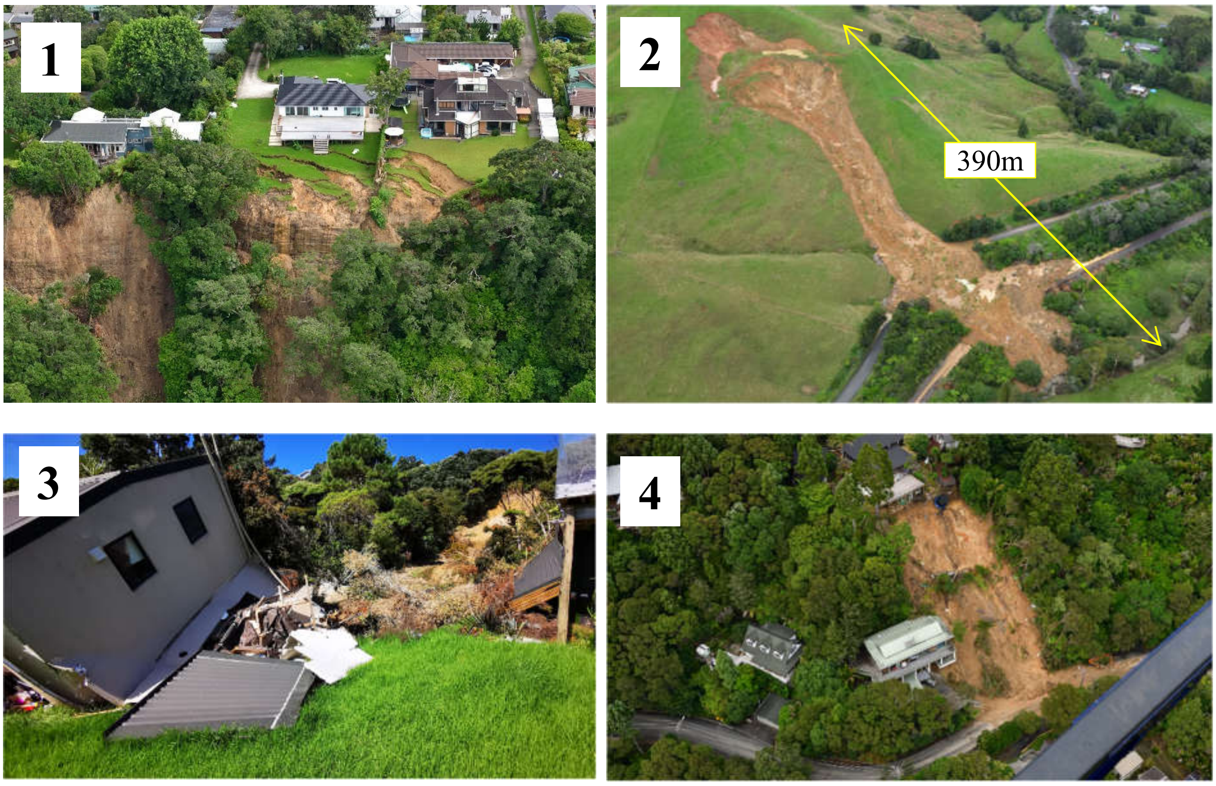

Figure 6. Examples of Auckland landslides triggered in 2023 which affected homes and infrastructure. 1) Typical cliff-top failure in residual deposits of the East Coast Bays Formation. 2) Rotational failure of residually weathered clay transitioning to a flow inundating a road and main railway line in north Auckland. 3) A two-storey home pushed about 20 m off its foundations in Muriwai. 4) Shallow translational slide common on steep slopes in west Auckland.

Initial helicopter reconnaissance (e.g. Fig 6.4) allowed the extent of the damage to be quickly confirmed, vulnerable areas identified and enable responders to focus efforts on the areas of greatest need.

3.2 Rapid Building Assessments

Rapid Building Assessments (RBA) are a brief evaluation of individual buildings and their immediate surrounds for damage, usability and hazards exposure. The goal is to assess immediate risk to public safety. The key purpose of the RBA is to determine a building is safe to occupy, land instability poses a potential risk and if the building itself poses a potential risk to people and other property. The assessment is carried out quickly (typically 20 mins per building) to allow a larger number and coverage of affected properties be able to be assessed. Placards were placed on the properties assessed. Placards are a legal notice which cannot be lawfully removed or changes without expressed permission from the building consent authority.

In Auckland, about 7,000 homes were assessed for damage and of these over 600 homes were given "Red Placards" meaning they were unable to be accessed and over 2,000 were given "Yellow Placards" meaning access was restricted. The remainder received "White Placards" meaning that the building has suffered light or no damage and could be used (Auckland Council, 2023). Geo-professionals provided technical input to provide their opinion on geohazards and their risk to properties. These informed the decision made on the placard given. In New Zealand many geo-professionals are trained for this function, and follow guidance set out in the Field Guide: Rapid Post Disaster Building Usability Assessment – Geotechnical (Ministry of Business, Innovation & Employment, 2018).

3.3 Drone surveys, LiDAR and remote imagery

Auckland Council was fortunate to have access to skilled in-house drone operators, and to be in the middle of a LiDAR campaign using helicopter-based equipment. These were re-deployed into emergency response and collected very valuable data from the hardest hit areas.

Figure 7. Example 3D model from drone from Muriwai, collected and published three days after the landslides.

Pix4D Mapper cloud was used for 2D orthomosaic stitching and 3D model reconstruction from drone data, enabling very rapid model production and sharing. These datasets were published online (https://landslides.nz/data/) to allow free access for infrastructure providers, emergency services and others, and proved very useful in assessing geomorphology, landslide run-out and the Fahrböschung (F) angle.

Repeat LiDAR surveys were conducted in areas of greatest concern at weekly intervals to identify any ongoing movement and determine if homes at the margins of landslides, or in potential run-out impact zones, could be re-occupied by changing their RBA placard. This high-quality data was essential in supporting this high-consequence decision making.

Satellite imagery was also procured but was less valuable than anticipated. High levels of cloud cover meant that getting cloud-free images took several months. The end products were useful for retrospectively mapping 150,000 landslides across New Zealand, but were not available in time for meaningful use in response. The resolution and georeferencing was lower than images collected using helicopters or fixed-wing aircraft.

3.4 Communication with community

Communication with affected homeowners proved to be a key challenge. In Muriwai, because it was the community with the highest concentration of affected homes, Auckland Council held a series of public meetings to explain what was happening, and issued 24 newsletters between March and August 2023 (Auckland Council, 2023). An example of the type of communications that were particularly well received is available at https://www.aucklandcouncil.govt.nz/recovery-extreme-weather-disasters/Documents/8-march-muriwai-community-newsletter.pdf

When new technical results were ready, they were issued to the community in draft for feedback, and a combination of public presentations and one-on-one meetings with geotechnical specialists were held to explain the implications and gather feedback. Local community groups provided a valuable sounding board and helped liaise with members of the community that were hard to reach. The public sessions were supported by other disciplines such as experts in RBA placarding, insurance, mental health, and financial advisors. Early frustration, anger and fear was broadly alleviated by this approach, and a good degree of trust was built, although there were some exceptions.

For other areas of Auckland, communications were less consistent. Because the affected homes were widely distributed, public meetings were not very effective and it was hard to create newsletters that were relevant. This led to people feeling isolated and ignored. The most successful channel was through webinars and pre-recorded YouTube videos. These were used to explain the technical approaches and to answer frequently asked questions while providing time flexibility to the audience, allowing them to view the content at their convenience.

Later, "Recovery Navigators" were employed to provide a single point of contact for each affected homeowner. These non-technical customer facing staff were supported by the in-house geotechnical team to be able to give some technical support, and to triage questions from homeowners so they could be efficiently answered without delaying other risk assessments. This was more successful than the earlier approaches, it took some time for the Recovery Navigators to be knowledgeable enough about the process to add significant value, and some early interactions with homeowners did not go as well. Detailed, early technical training for these communications staff is essential to success. Direct contact between affected homeowners and technical specialists gave by far the best outcome in most cases, but was challenging to resource. It is recommended that in significant recovery efforts that engineers and scientists with good communication skills are engaged to undertake this role.

3.5 Building a response team

In addition to the standard response, two elements were added to the team. Firstly, in April 2023 a geotechnical advisory panel of five technical experts was engaged. Their role was to review the methodologies being used, the scopes given to suppliers, and key deliverables. They also provided ad-hoc advice which was particularly valuable on more controversial decisions. The panel was technically balanced with two geotechnical engineers, two engineering geologists, and an engineering geologist/hydrogeologist. The panel was convened as required and worked together to compile advice for the Council team.

Secondly, in May 2023 external project managers were procured. It had quickly become apparent that the scale of mobilisation needed to implement the government direction would exceed the capacity of in-house project managers, and that using geo-professionals for project management would distract them from delivering the important technical work.

4 Conclusions and lessons

4.1 Systems and processes

Local Authorities can position themselves to manage situations like these by ensuring that business-as-usual systems are designed with disaster response and recovery as part of their core functionality, and have in place the right processes to enable these systems to be scaled up.

This particularly applies to the rapid collection of data, including aerial photography and remote sensing. The ability to quickly collect, process, interpret and share this data is highly valuable. It is challenging to set up the appropriate contracts and systems during an emergency response, so these need to be planned in advance.

4.2 Communications

Clear, frequent communications explaining the technical decisions will be needed to bring members of the community on the journey as information becomes available. Having technical experts available to support communities (alongside other disciplines offering support for mental health, financial advice etc.) creates much better outcomes.

4.3 Resources and expertise

Access to the right skills at the right time can make a significant difference to the recovery effort. Auckland was fortunate to have access to skilled geo-professionals, many of whom were trained in RBA. In particular, the setting up of a Geotechnical Advisory Panel and engaging project managers added significant value.

4.4 'Gut-feel' and data-led decision-making

Many early decisions made with limited information proved to be remarkably accurate such as the application of the Fahrböschung (F) angle in Muriwai. In the immediate response rapid decisions were needed to determine which homes to evacuate through the RBA process. The extent of the seven main landslides in Muriwai were mapped, and the maximum and minimum F-angle ascertained. This was then mapped across the remainder of the affected area and each home assigned an RBA placard reflecting the risk.

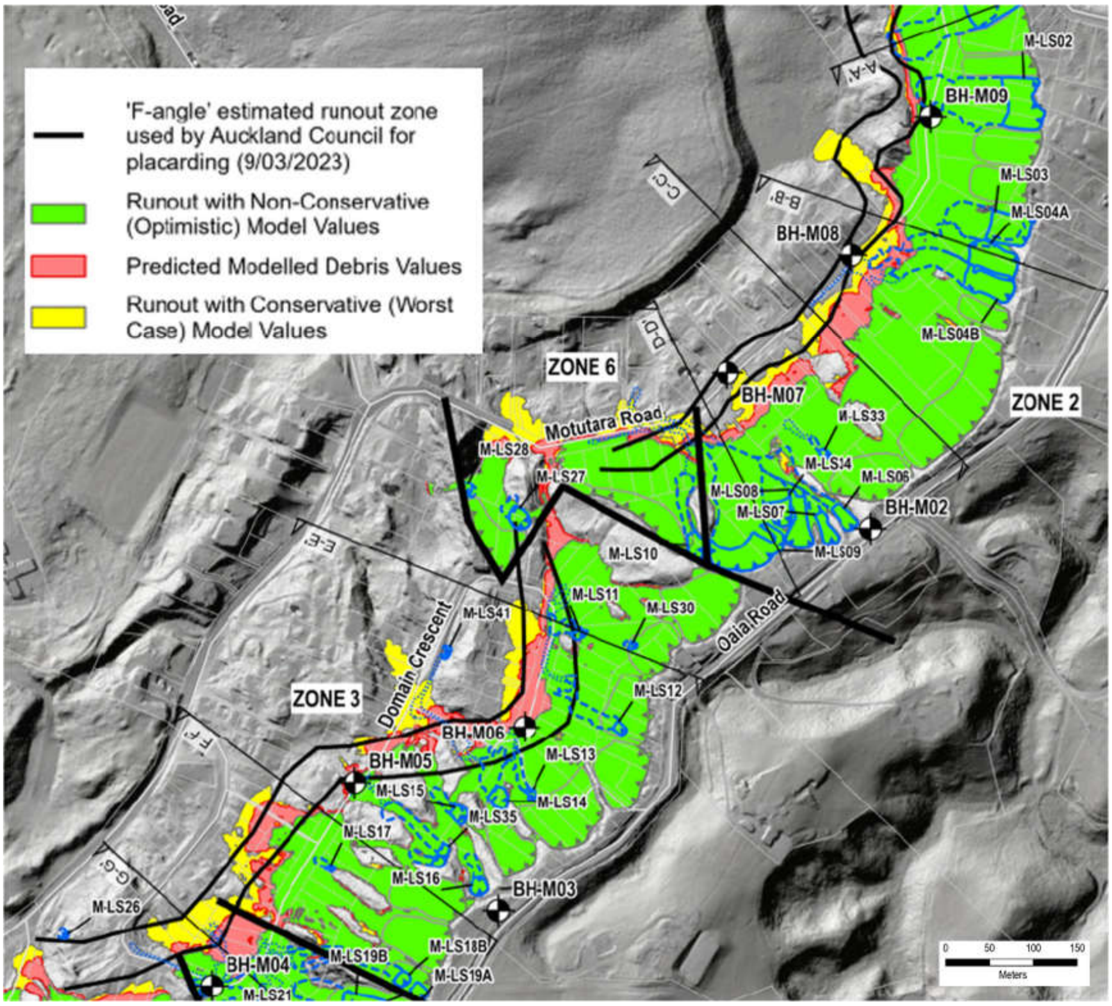

Figure 8. Best-case and worst-case F-angle (parallel black lines) mapped over one weekend shortly after Cyclone Gabrielle, compared with results of detailed RAMMS modelling (coloured zones). Mapped landslides shown in blue (GHD, 2023). Oaia Road follows the edge of the steep, northwest-facing escarpment.

Later, detailed geotechnical assessments and RAMMS modelling was undertaken. This took nearly six months but gave broadly similar results. Additional rigour provided by more detailed analyses was essential to give confidence to homeowners and politicians, but the similarity in outcome highlights the value of rapidly applied expert judgement in emergency situations (Fig 8).

Acknowledgements

Our thanks go to the people of Auckland who have endured huge challenges in 2023 and 2024 for their patience while we undertook this work, and to the many members of the geotechnical community who helped in the response. Many geo-professionals gave their time free of charge in the immediate aftermath to help the RBA process, and without your goodwill and expertise many people would have been at risk for far longer. A huge number of people have worked on the disaster response and recovery, and it would be impossible to thank them all.

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