Landslides triggered by the "Tasman Tempest" rainfall event, March 2017, in southeast Auckland, New Zealand

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ABSTRACT

The Tasman Tempest storm event was generated by a tropical cyclone originating in the Tasman sea, bringing extreme rainfall to the North Island of New Zealand on the 7th to 12th of March 2017. The storm consisted of three high intensity rainfall pulses with the first occurring over the 7th to 8th, the second over 10th to 11th and the final pulse on the 12th of March. The storm caused thousands of landslides, flooding and power outages creating major disruption for people in southeast Auckland, with Hunua, Clevedon, Kawakawa Bay and Waiheke Island impacted the worst. The heaviest rainfall occurred south and east of Auckland over a 24-hour period from the 7th to 8th of March when 266 mm was recorded over 24 hours; an annual return interval that exceeded a 1 in 100-year event (HIRDS). The extensive landslides in the Hunua ranges south of Auckland compromised the water supply collection facilities in this area when silt from landslide deposits entered the reservoirs and overwhelmed the filtration capacities of the system.

Landslides initiated by the storm were mapped using Google Earth imagery and high-resolution aerial photographs. Landslides were mapped as points across the 882 km^2 study area and in greater detail as polygons within a smaller study window (source areas, debris trails and debris deposits) using the Kaikoura landslide inventory mapping method (Massey et al. 2018). Gauge corrected rain radar data supplied by MetService was used to quantify rainfall for the storm and enable rainfall estimates to be made for individual landslides.

Landslides were most commonly triggered across slopes which had a slope angle of 20–40°. Landslides were triggered predominantly on slopes that were underlain by greywacke, a reflection of the dominant rock type in the study area. Land cover consisted of native forest, forest plantations, pasture, scrub and other (settlements). The highest frequency of landslides was observed on pasture as expected, however, the highest landslide density was recorded within forest plantations (as mapped in 2012/2013). Significant areas of forest have been logged since LCDB v4.1 mapping was completed in 2012/3 which is not reflected in the 'Forest' category. It is probable the landslides occurred in recently logged areas.

Maximum rainfall for the 24-hour period was between 260–280 mm, although this rainfall was located over the Hauraki Gulf. The maximum rainfall for a mapped landslide was in the range 200–220 mm. The highest density of landslides broadly coincided with the most rainfall of 180–200 mm. An exception was a small area near the coast (Waitawa Regional Park) where higher rainfall of 200–220 mm did not result in a higher density of landslides. The reason for this has not been investigated but may be due to coastal slopes being more resistant to high-intensity rainfall events because they are exposed to coastal processes.

KEYWORDS

Tasman Tempest 2017, Auckland, New Zealand, rain radar, landslides, flooding, Hunua Ranges

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1.0 INTRODUCTION

1.1 Background and Weather Conditions

During the week of the 7th to 12th of March 2017, the upper North Island of New Zealand experienced three extreme heavy rainfall pulses that broke multiple rainfall records, and resulted in landslides, flooding and damage to homes and infrastructure. The rainfall was caused by a slow-moving low-pressure system that originated in the Tasman Sea (the "Tasman Tempest") and transported moist air in a clockwise direction from the tropics. The slow-moving system was halted by a "blocking" high pressure system to the south of New Zealand. The stationary low and very moist air resulted in three pulses of heavy rainfall during the six-day period of the storm (NIWA 2017).

On the 7th to 8th March 2017, southeast Auckland and the Coromandel Peninsula region received 266 mm of rainfall over 24 hours, an event which has a return period exceeding a 1 in 100-year event (HIRDS). Notably at 12 pm on the 7th of March the maximum rainfall of 100 mm was received within an hour, which has an estimated return period of 670 years (HIRDS). Hunua, Clevedon, Kawakawa Bay and Waiheke Island experienced flooding and slips, with around 1000 homes in southeast Auckland experiencing power outages. Major flooding in Clevedon caused significant loss of livestock in the area (Noll 2017).

Intense rainfall over a short period of time in the Hunua Ranges caused extensive landslides resulting in damage to farms, commercial forestry blocks and dense native bush. As a consequence, elevated suspended sediment levels and turbidity occurred within the five water reservoirs in the Hunua Ranges which supply 60% of Auckland's water supply (Watercare 2017). This caused the Ardmore treatment plant to run at half of its maximum capacity with the risk of releasing partially treated water (Watercare 2017).

On the 10th to 11th of March 2017 a second heavy rainfall pulse occurred in eastern Auckland, Coromandel and Northland that caused further flooding and left thousands of people without power. Auckland airport experienced its equal-wettest March one-hour rainfall record with 27.6 mm recorded. Multiple road closures occurred in Auckland due to surface flooding and state highways SH25, SH26A and SH26 in Coromandel were closed due to landslides (GeoNet 2017; NIWA 2017).

The final rainfall event on the 12th of March 2017 saw localised downpours impact Auckland suburbs, with multiple areas of flooding. The suburb of New Lynn received 60 mm of rain within two hours (Noll 2017) and was severely impacted when a damaged culvert resulted in a sinkhole that caused damage to infrastructure in the vicinity.

1.2 Study Area

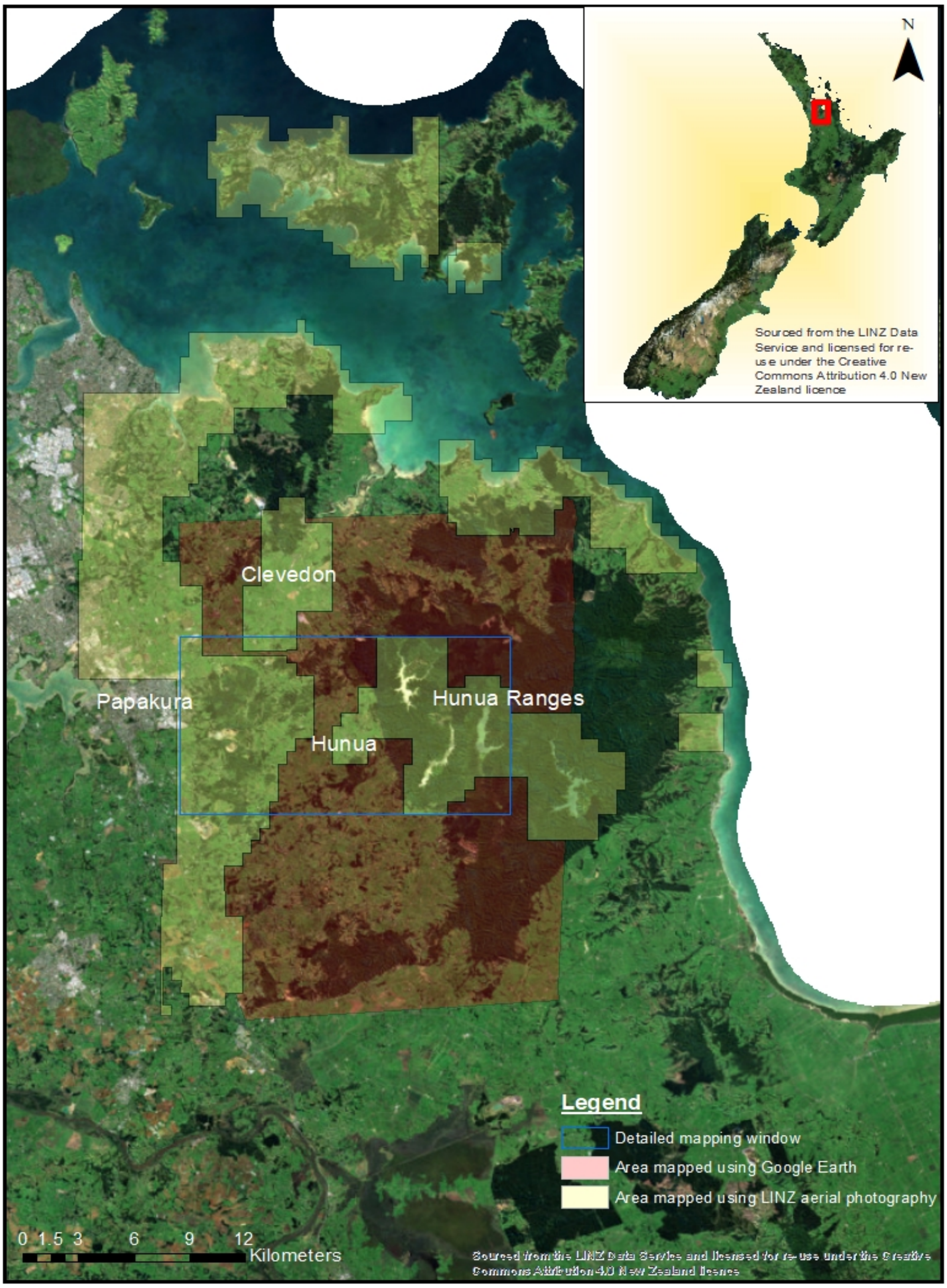

Figure 1.1 Location of study area, detailed mapping window and mapping imagery type with respect to New Zealand as a whole

The study area (Figure 1.1) is located southeast of Auckland in the Hunua Ranges and surrounding areas and extends offshore to include the eastern half of Waiheke Island. Topography is varied across the region, with the rugged hillslopes of the Hunua Ranges largely covered in dense native bush and forestry plantations (Figure 1.2). The region is underlain by a variety of rock types ranging from predominately finely bedded siltstones and sandstones (greywacke) of Jurassic age to Holocene river deposits. Volcanic units of the Auckland and South Auckland volcanic fields are present in some places (Figure 1.3). Highly populated areas such as Papakura exist to the east of the Hunua Ranges, with smaller settlements located close by such as Clevedon and Hunua (Figure 1.1).

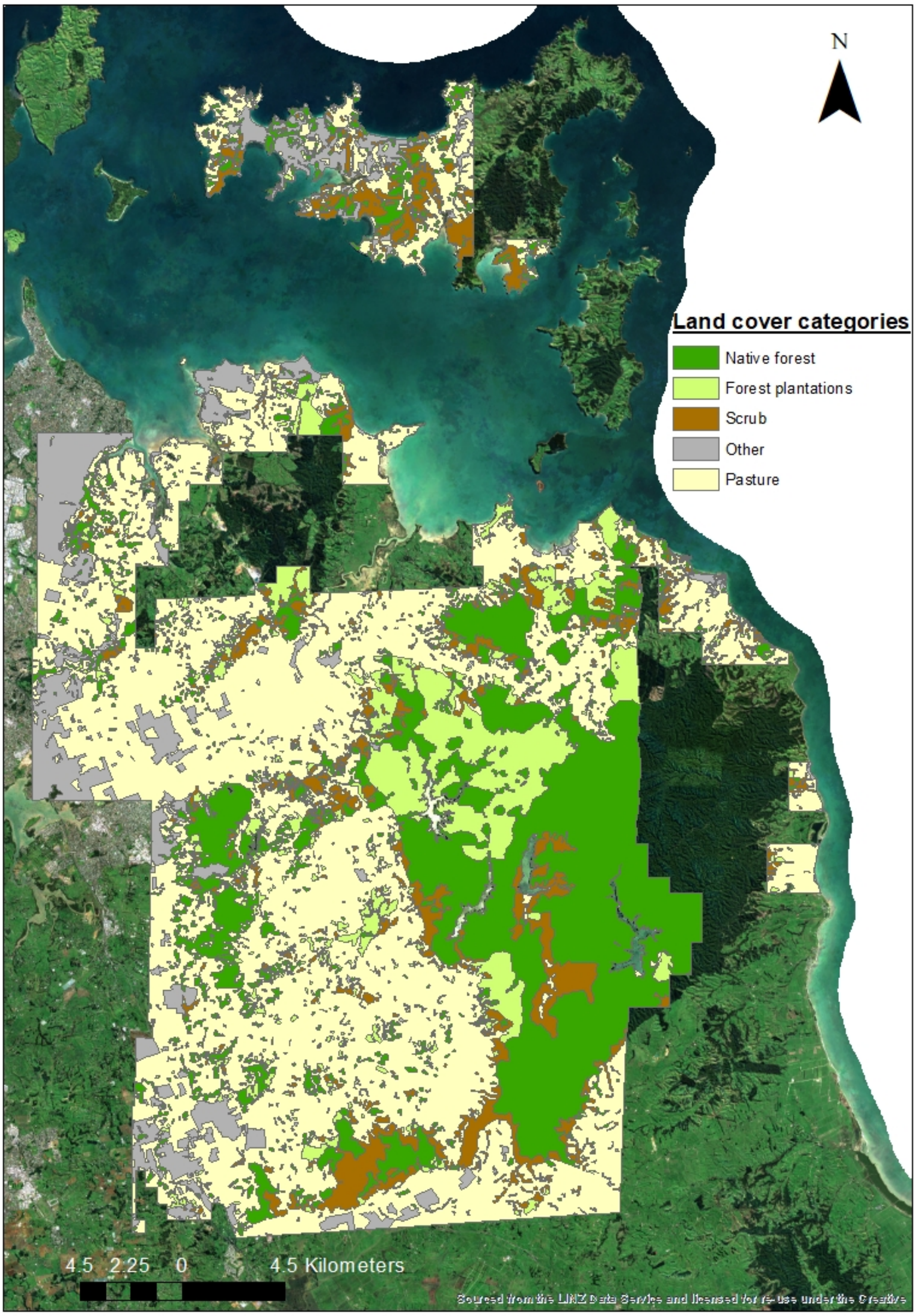

Figure 1.2 Land cover categories in the study area (Data from LCDB v4.1, lris.scinfo.org.nz/)

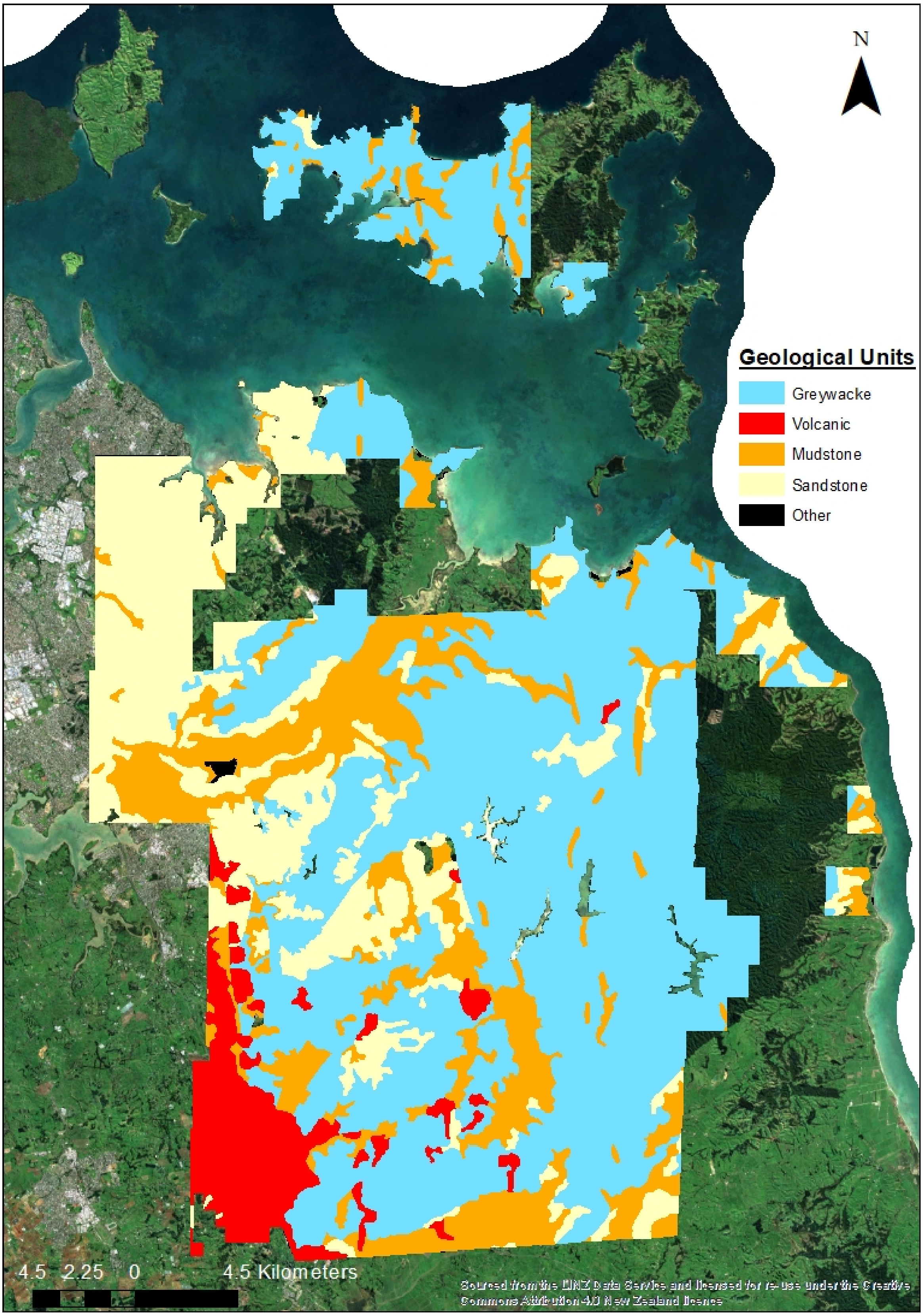

Figure 1.3 Distribution of different geological units in the study area. Data was simplified from the 1: 250 000 Geological Map of New Zealand (QMap, GNS Science 2014).

1.3 Scope of Report

The focus of this study was to map and undertake basic analysis of the landslides initiated by the Tasman Tempest storm event. A landslide inventory has been generated for the storm event using ArcGIS. Landslides were mapped as points across the whole region and a small study window was mapped at a more detailed level using the Kaikoura earthquake landslide inventory mapping methodology (Massey et al. 2018). Rain radar data was used to quantify the amount of rainfall which fell during the storm and allowed rainfall estimates for individual landslides to be made. The landslide distribution for the mapped area was overlaid onto various spatial datasets including: landcover, rock type and slope GIS layer data extracted from a DEM to analyse the factors controlling the landslide distribution. The results have been summarised in the form of graphs and tables from data analysed, with landslide susceptibility briefly discussed for the region.

2.0 DATASETS AND METHODOLOGY

2.1 Datasets

Google Earth imagery and high-resolution aerial photographs were used to map landslides over an area of 882 km^2. The area covered by each imagery type is summarised in Table 2.1. Initially Google Earth was accessed for preliminary imagery of the area using the time slider tool to view pre-event (02/2017) and post event (3/2017) Digital Globe imagery.

Pre- and post-event aerial photography was acquired from the Land Information New Zealand (LINZ) data service website (https://data.linz.govt.nz/). Pre-event 0.5m resolution imagery was acquired over 2010–2012 period, (Auckland 0.5 m rural aerial photos-2010–2012). Post-event 0.075 m resolution imagery was acquired in 2017, titled (Auckland 0.075m urban aerial photos (2017)). Post-event JPEG tiles were mosaicked together to create a compressed ECW file for analysis in ArcMap.

Table 2.1 Areas covered by different imagery sources in this study.

Imagery Source	Date of capture	Area km2
Google Earth	14 March 2017	375.5
LINZ	Summer 2016–2017	506.5
Total		**882**

Elevation data was derived from Digital Elevation Model (DEM) data accessed from the LINZ data service website (https://data.linz.govt.nz/). The New Zealand 8 m DEM (acquired in 2012) was initially used to calculate slope angles. This was in the form of a raster layer, reclassified to into slope intervals of 10°. A second 1 m resolution DEM derived from 2010/2011 LiDAR data was provided by Auckland Council and was used as a hill shade layer to check slope orientations and geometry for comparison with aerial photography.

Land cover information was downloaded from the Land Cover Database-v4.1 (LCDB-v4.1) which has polygons for each land cover category at 1:50,000 scale. Data was accessed from the Land Resource Information Systems Portal (LRIS: https://lris.scinfo.org.nz/) and consisted of land cover information mapped in 2012/2013. Categories were simplified into the following groups for this study: forest plantations (mature and harvested), native forest (Indigenous forest and hardwoods), pasture (high and low producing grassland), scrub (mixed shrub land, gorse and/or broom and Manuka and/or Kanuka) and other (settlements, orchards/vineyards/crops and sand/gravel).

Geological information was obtained from QMap in the form of a GIS feature class map created by GNS Science. QMap consists of the most up to date geological dataset for New Zealand at 1:250,000 scale (GNS Science 2014). Due to the wide variety of geological units present, rock types were simplified into the following groups: greywacke (Waipapa Composite Terrain), mudstone (Te Kuiti Group), sandstone (Waitemata Group), volcanic (Undifferentiated Kerikeri Volcanic Group) and other (Holocene landslide and ocean beach deposits).

MetService provided gauge-corrected rain radar data as 1-hour rainfall total text files. A python script was used to process the txt files, that projected data to NZGD 2000 New Zealand Transverse Mercator (NZTM) coordinate system, then converted it to raster format which was then reclassified. Maximum 1-hourly rainfall amounts were added together using the raster calculator tool in ArcMap, producing down-sampled 10x10 m resolution raster layers of the maximum rainfall for various periods during the storm. 20 mm rainfall contours were then manually interpreted for the 24-hour storm total.

2.2 Methodology

The main study area (of 882 km^2) in south east Auckland is covered by Google Earth and LINZ imagery as shown by the polygons in Figure 1.1. Basic mapping (using points) was undertaken over this large area and more detailed mapping (polygons) was completed within the small study window shown by the blue polygon in Figure 1.1.

Landslides in the study area (Figure 1.1) were initially mapped using points placed at the top of landslide crowns to record their location. This was done using Google Earth imagery and then aerial photography to fill in the missing areas. Points mapped on Google Earth were transferred to the GIS program ArcMap but experienced alignment issues on the underlying aerial imagery. These were cross-checked, and any discrepancies were resolved to ensure accuracy of landslide locations.

The result of the low detail (point) mapping above gave an inventory of landslides triggered by the storm, identified by their crown location. Using the Kaikoura landslide inventory mapping method (Massey et al. 2018) a small study window (179.5 km^2) was mapped in detail to further expand the inventory (Figure 1.1) and obtain morphological information about the landslides. For each landslide the following features were collected.

- Point at the crown of the landslide
- Polygon drawn around the source area of the landslide
- Polygon drawn around the deposit area of the landslide debris
- Landslide attributes unique to each landslide source and deposit

In the detailed study window, some landslides were obscured by vegetation or shadows and could not be mapped, however, a representative area of detailed mapped landslides was produced for the small study window with 898 crown points, 632 source area and 274 deposit polygons mapped.

To analyse factors controlling the landslide distribution, mapped landslides were overlaid on various spatial datasets within ArcMap. The mapped landslide distribution was overlaid on land cover, geological and slope layers using the Intersect tool in ArcMap to extract information unique to the location of each landslide crown.

Rainfall contours were clipped to the extent of the study area polygon (Figure 1.1), to calculate the area occupied by each rainfall interval. The number of landslides in each rainfall interval were summed and divided by the area occupied by each rainfall interval to obtain a landslide density for each rainfall interval. Data extracted from ArcMap was exported into Microsoft Excel and summarised using frequency tables for specific attributes.

Land cover, rock type and slope information were summarised using pivot tables, using the simplified groupings discussed in section 2.1. Landslide densities (landslide per km^2) for each layer were calculated by dividing the area occupied by each category by the frequency of landslides within the category. The influence of slope angle on landslide occurrence was assessed by calculating the landslide density in each slope category by dividing the frequency of landslides within each slope interval by the area occupied by each slope interval for the whole study area.

3.0 RESULTS

3.1 Landslides Triggered by the 'Tasman Tempest'

Landslides were triggered on pasture, forest, and indigenous forest. Most landslides were small shallow translational slides and flows (Figure 3.1 and Figure 3.2). In some areas, these coalesced in the drainage network to form debris flows that travelled down the drainage network (Figure 3.1). The largest landslides were commonly located on recently harvested and mature forest plantations. Debris flows occurred most commonly on these recently clear-felled areas. Because no fieldwork was undertaken as part of this study no quantitative assessment of soil depths could be made.

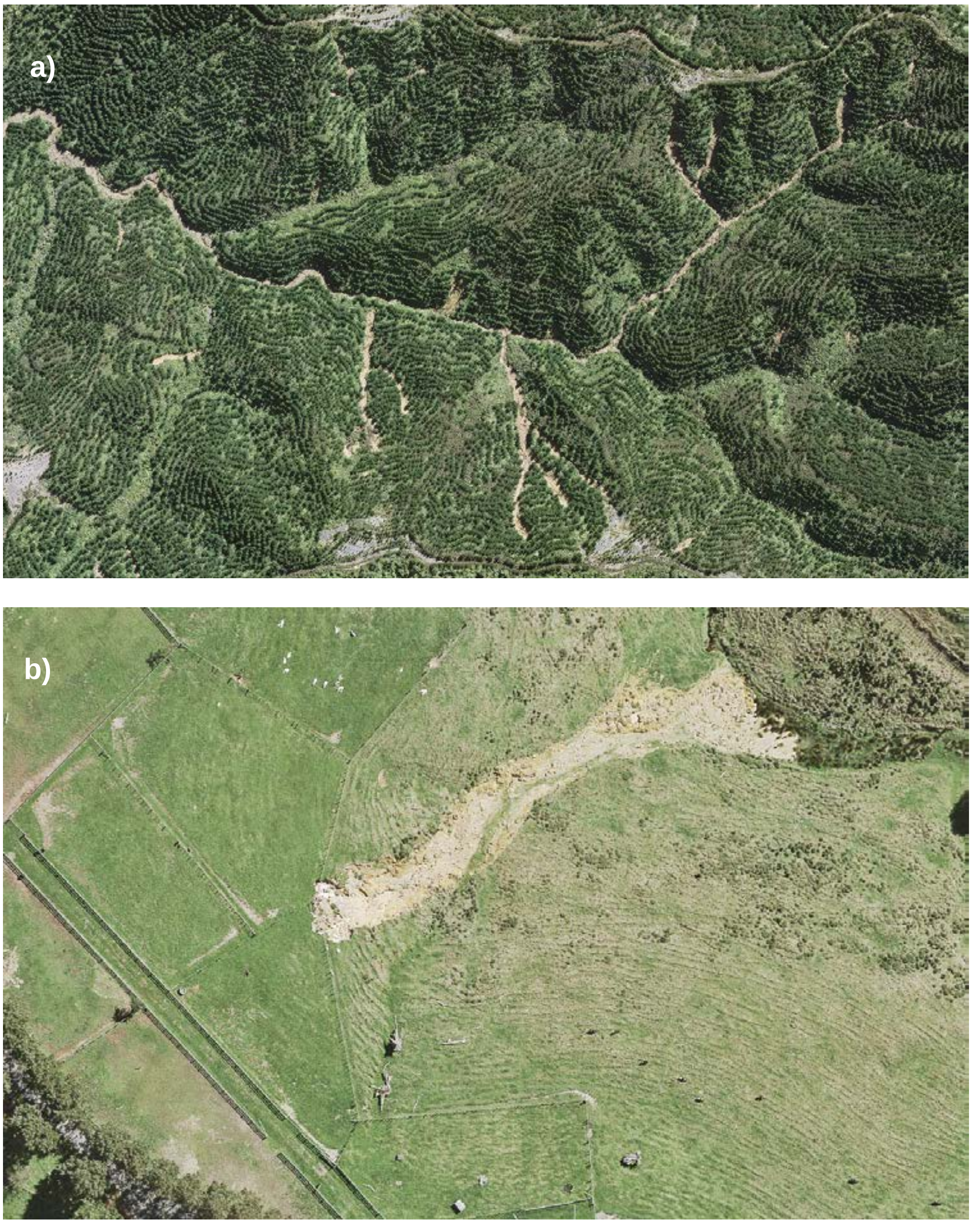

Figure 3.1 a) Debris flow triggered within young forest plantations. b) Translational flow within pasture.

Figure 3.2 Small debris flow within native forest bordering on forest plantations.

3.2 Landslide Density and Rainfall

Rainfall statistics for the Tasman Tempest from rain radar data are summarised in Table 3.1. The maximum 24-hour rainfall total was 266 mm which exceeded the 1 in 100-year event return period, however, this was located offshore near Waiheke Island (Figure 3.3). The maximum rainfall received on land was 200–220 mm and had an average return period of approximately 36 years.

Table 3.1 Rainfall statistics for the Tasman Tempest from rain-radar data. Also shown is the maximum on-land rainfall for landslides extracted from rain-radar data. Return periods and the standard error was calculated using data from NIWA's HIRDS database (https://hirds.niwa.co.nz/).

Rainfall period	Max Rainfall (mm)	Return Period (yrs)	Standard error (yrs)
1 hour	100	670	~ 18
3 hours	131	182	25
12 hours	188	64	35
24 hours	266	107	33
24 hours (rainfall from landslides)	200–220	36	8.5

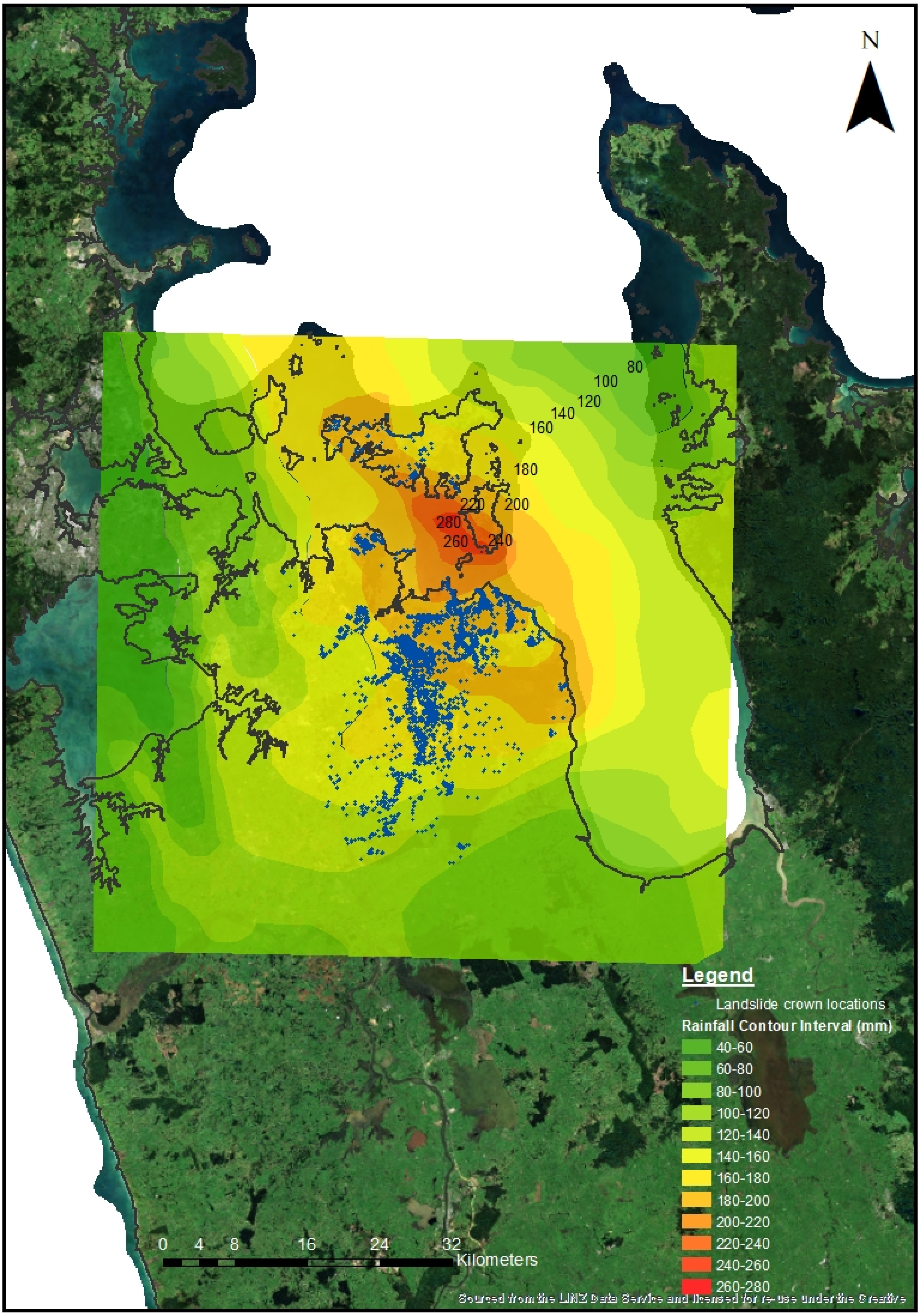

Figure 3.3 Map showing rainfall contours and the location of landslide crowns (blue).

Landslides triggered during the 24-hour storm are shown in relation to the rainfall contours in Figure 3.3. The landslide density for each rainfall contour is shown in Figure 3.4. Landslide density increased with increasing rainfall and peaks at 21 landslides per km^2, demonstrating most landslides occur within the 180–200 mm rainfall interval. The lowest density occurred in the contour of 100–120 mm with a density of 0.4 landslides per km^2. An anomalously low landslide density of 2.7 per km^2 was recorded in the area of the maximum rainfall contour, which is discussed in section 4.

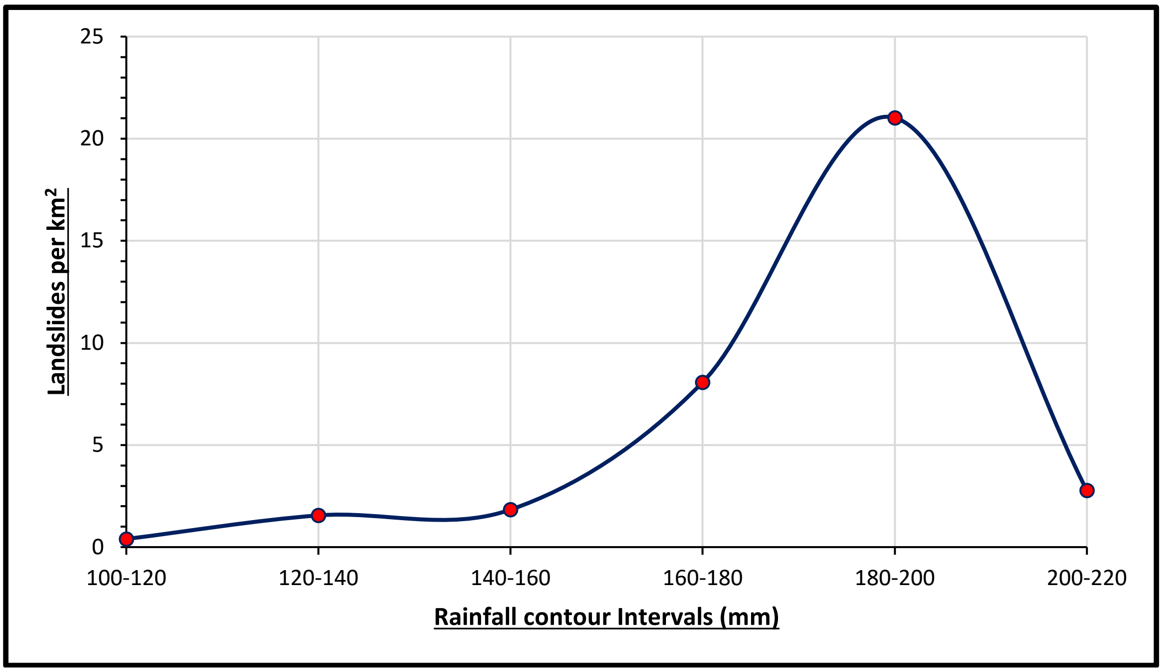

Figure 3.4 Landslide densities within specified contour intervals for maximum 24-hour rainfall values.

3.3 Factors Controlling Landslide Distribution

Landslide distribution is controlled by numerous factors but four main components: geology, land cover, slope angle and rainfall have been investigated in this study.

Table 3.2 lists the number of landslides mapped in each geological unit (crown points), the percentage of the total number of landslides in each geological unit and the number of landslides per square kilometre. The study region is dominated by greywacke which covers a total area of 444.3 km^2, and also the highest number of landslides at 6052 (93.2 %). Sandstone and mudstone also cover significant areas but have fewer landslides and much lower densities of 0.9 and 1.6 landslides per km^2, respectively.

Table 3.2 Rock type statistics for landslides within the study area.

Rock type	Area of geological unit (km^2)	Percentage of study area occupied by rock type (%)	Number of Landslides (n)	Percentage of landslides in geological unit (%)	Landslide density (n/km^2)
Greywacke	444.3	54.3	6052	93.2	13.6
Mudstone	149.6	18.3	247	3.8	1.6
Volcanic	52.9	6.5	34	0.5	0.6
Sandstone	167.4	20.4	146	2.2	0.9
Other	4.6	0.6	15	0.23	3.3

The distribution of landslides in relation to land cover is summarised in Table 3.3, which lists the number of landslides mapped, percentage of the total number of landslides in each land cover category and the number of landslides per square kilometre. The largest number of landslides took place on pasture (49.8%), with a large percentage within forest plantations (30.8%). Native forest also had a notable percentage of landslides at (11.6%). Landslide density was the highest in forest plantations at (26.6 landslides/km^2). Landslide densities were similar on pasture (8.1 landslides/km^2) and scrub (7.1 landslides/km^2) and much less than on forest plantations.

Table 3.3 Land cover statistics for landslides within the study area.

Land cover category	Area of land cover category (km^2)	Percentage of study area occupied by land cover category (%)	Number of landslides (n)	Percentage of landslides in land cover category (%)	Landslide density (n/km^2)
Forest plantation	75.2	9.2	1998	30.8	26.6
Native forest	203.1	24.9	756	11.6	3.7
Pasture	400	49	3233	49.8	8.1
Scrub	68.4	8.3	480	7.4	7.0
Other	69.4	8.5	26	0.40	0.4

Landslides were preferentially triggered on slopes between 20–40°. Figure 3.5 shows the percentage of landslides that occurred on different slope categories in the study area in relation to the area occupied by the slope categories and demonstrates that the slopes landslides occurred on do not follow the same distribution as slopes in the study area. The slope represents the slope angle at the crown of the landslide. Figure 3.5 indicates that landslides preferentially occurred on steeper slopes (20–40°), even though these slopes occupied a smaller proportion of the study area. As expected, hillslopes with angles between 0–10° had the least landslides. Less landslides occurred on the steepest slope categories, however disproportionately more landslides occurred on these slopes compared to their proportion of slopes in the study area (Table 3.4). The highest landslide density occurred on slope angles between 30–40° (22.5 landslides/km^2), with 20–30° (15.7 landslides/km^2), 40–50° (17.0 landslides/km^2) also having notable densities. As expected, lower landslide densities were observed on lower slope angles, 0–10° (0.9 landslides/km^2).

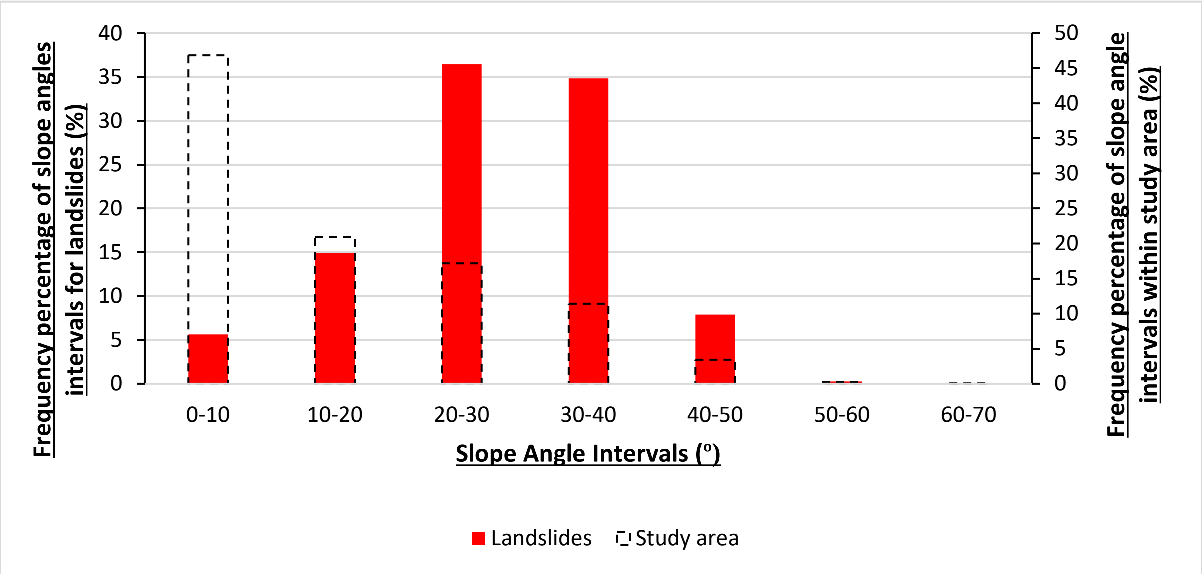

Figure 3.5 Slope angle percentages for the study area plotted with slope angles from mapped landslides.

Table 3.4 Slope statistics for landslides and the overall study area.

Slope Angle Category (°)	Frequency of Landslides (n)	Area of Slope Category (km^2)	Landslide density (n/km^2)
0–10	366	413.6	0.9
10–20	971	185.0	5.2
20–30	2371	151.5	15.7
30–40	2268	100.7	22.5
40–50	513	30.1	17.0
50–60	117	2.1	8.0
60–70	0	0.0	0

3.4 Detailed Study Window Landslides

Landslides in the detailed mapping window consisted of shallow soil translational slides (Figure 3.1) and debris flows (Figures 3.1, 3.5, 3.6 and 3.7). Landslide source and deposit areas are summarised in Table 3.5. Deposits are generally larger than source areas, especially those of debris flows, which is demonstrated by the scar to tail ratio of 0.66. Deposits from the mapped landslides had a higher maximum area then landslide source areas, likely because of debris flows transporting landslide material further downslope and into the drainage network.

Landslide depths were not measured in this study but data from Selby (1976) in the Hunua Ranges suggest an average head scarp depth of 0.89 m for landslides within forested areas. Using this value and the average landslide source area, we estimate an average eroded volume of (260.1 x 0.89) 231.5 m^3 of material per landslide. Applying this volume to all landslides mapped across the study area we estimate a total of volume of (231.5 x 6494) 1,503,360 m^3 of material eroded by landslides from this rainfall event.

Table 3.5 Landslide area statistics within the detailed mapping window.

	Minimum area (m^2)	**Maximum area (m^2)**	**Average area (m^2)**
Landslide source n= 632	4.3	1920.6	260.1 +/- 290
Landslide deposit n= 274	4.7	6590.2	393.4 +/- 724
Scar: tail ratio	-	-	0.66

Figure 3.6 Aerial photograph of a debris flow that took place within native forest. Note: green polygons = source area and pink polygon = deposit.

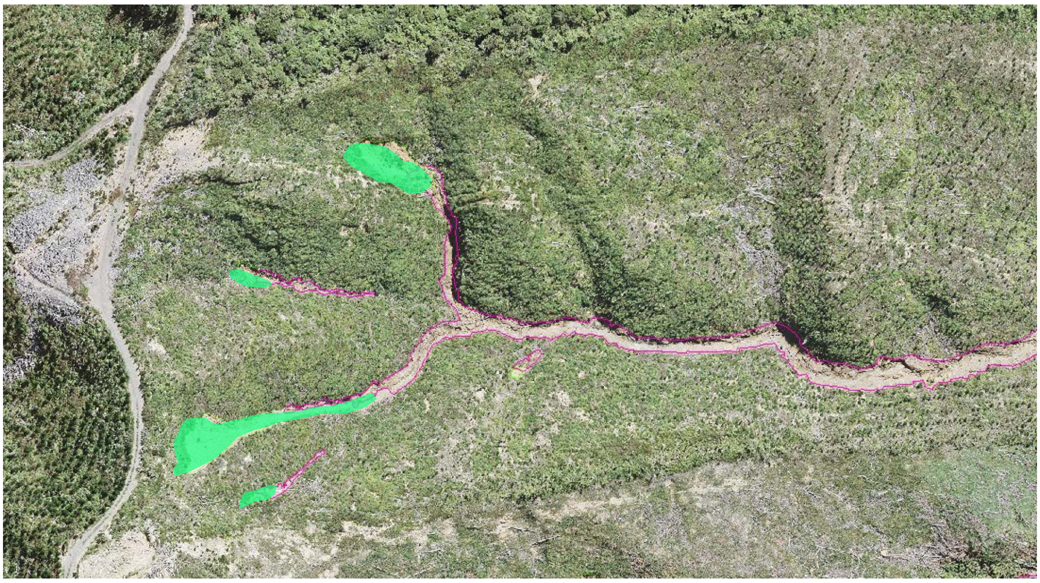

Figure 3.7 Aerial photograph of a debris flow that took place within young forest plantation block. Note: green polygons = source area and pink polygon = deposit.

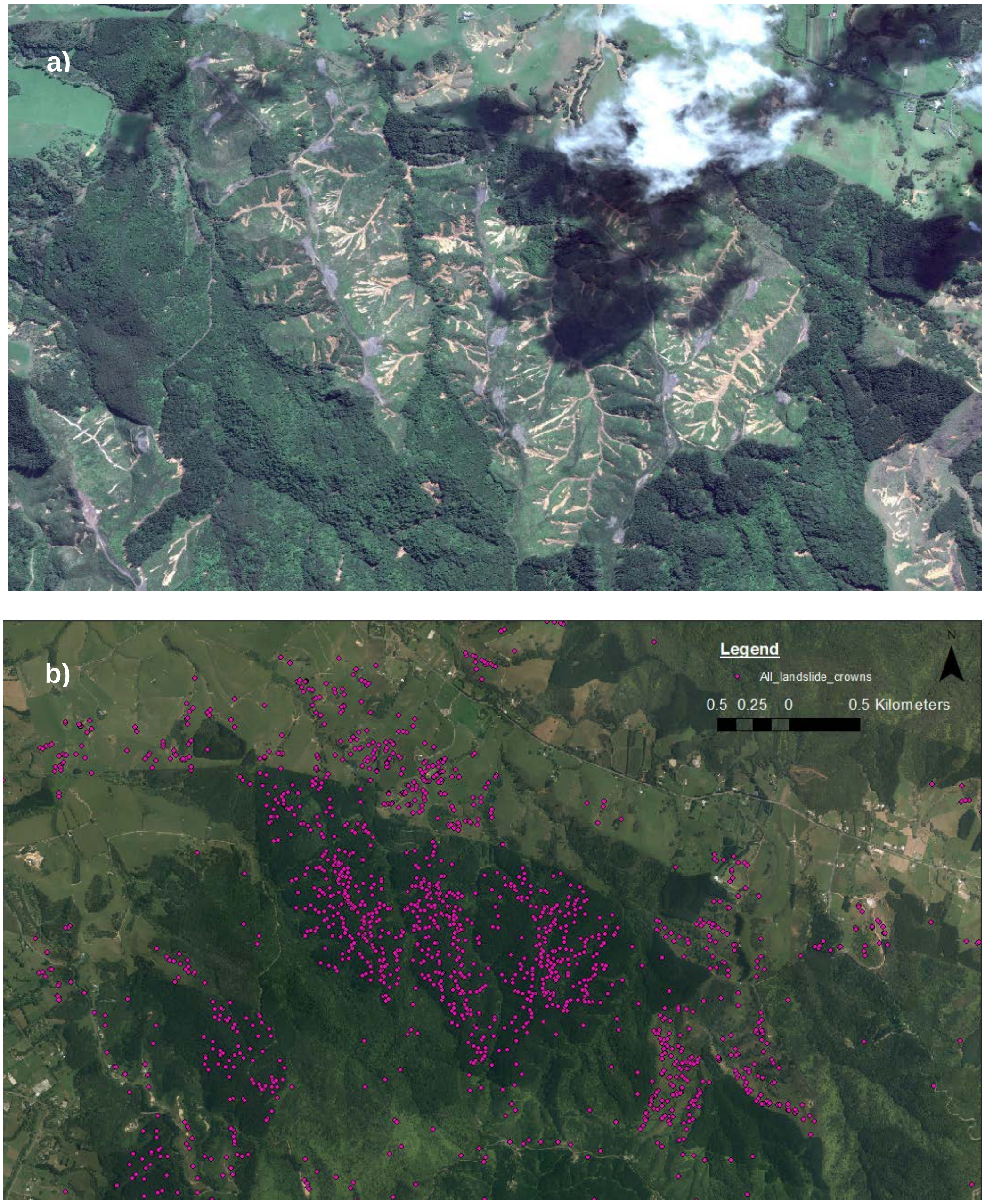

Figure 3.8 a) Post-storm Google Earth imagery demonstrating landslides and debris flows. b) Pre-storm LINZ aerial photography of the same area, with mapped landslide crowns overlaid.

4.0 DISCUSSION

In storm events we usually expect the highest landslide densities to be associated with the highest rainfall intensity, if other controlling factors (geology, slope angle and vegetation cover) are the same. A broad relationship between the highest density of landslides and the highest rainfall was established for this storm event, as the highest landslide density correlated with the 180–200 mm rainfall contour. However, there was an anomaly within the data where a small area located on the coast near Waitawa Regional Park received higher rainfall of 200–220 mm but did not have a high landslide density. Although not investigated here, the nature of this could be the result of coastal processes (such as wave action) creating slopes that are more resistant to rainfall triggers because the weakest sections of the slope are regularly removed by coastal processes. Despite this anomaly, 180–200 mm of rainfall over 24 hours was sufficient to cause widespread and concentrated landslides in the Hunua Ranges.

Landslides were most common in pasture and forest plantations (Table 3.4). Despite larger numbers of landslides within pasture, landslide densities were highest in forest plantations. This is in contrast to the results of previous studies in the region by Selby (1967) and Pain (1968) who recorded the highest landslide densities on pasture. This result can be attributed to the land cover information at the time being classed as forest plantation. LCDB-v4.1 mapping was undertaken in 2012/2013 and does not reflect areas of recent logging in the Hunua Ranges (Figure 3.6). This suggests that because logging has taken place, removal of the woody vegetation has made the area more prone to landslides as seen in Figure 9. This may explain the high density of landslides on slopes with “forest plantations”. Selby (1967) found that forest clearance in the region can cause a period of increased landslide activity due to decreased slope stability. Failure of forestry infrastructure such as logging roads, landings and skid sites has also been linked to increased numbers of landslides following production forest removal (Phillips et al. 2012).

Numerous debris flows occurred throughout the Hunua Ranges, including in the study area and the detailed mapping window (Figure 3.5 and Figure 3.6). The maximum area of landslide debris flow deposits was 6590 m^2. The large area is explained by the fact that debris flows have been generated and transported landslide debris long distances downslope (often into the channel network) extending their depositional features. Debris flows were mostly triggered in the recently logged forest plantations, most likely due to the removal of vegetation decreasing slope stability and land disturbance caused by logging activities (Phillips et al. 2012). However, debris flows also took place on slopes in native forest. Evidence of debris flows in both forest plantations and within native forest demonstrates that the intensity of rainfall during the storm was sufficient to cause debris flows on forested slopes in the region. Short-term (3hr) rainfall intensities of 30–40 mm/hr, or >10 mm/hr over longer periods (24 hrs) have been shown to trigger debris flows in other areas of New Zealand (Page 2013; Page et al. 2012; Basher 2010).

Rainfall events such as the Tasman Tempest are infrequent and therefore the resultant landslides which took place are a product of the extreme rainfall. The maximum 3-hour rainfall of 131 mm has a return period of approximately 182 years, and the 1-hour maximum of 100 mm has an estimated return period of 670 years. The most intense rainfall during the storm fell within a 3-hour period between 11 am and 1 pm on the 7th of March. The rainfall intensity during this three-hour period was 48 mm/hr. Given high intensity rainfall is required for debris flows to initiate in drainage channels (Page 2013; Page et al. 2012; Basher 2010, we hypothesise that most of the debris flows triggered during this time. It also suggests a rainfall threshold of 40–50 mm/hr to trigger debris flows on forested (plantation and indigenous) slopes underlain by greywacke in the Auckland region.

5.0 STUDY CONSTRAINTS

The mapping and analysis undertaken in this study has used a variety of data sources to extract landslide attributes and the rainfall characteristics that triggered their failure. The landslide inventory created has focused on areas with available imagery (Google Earth or LINZ) and therefore the landslide distribution across the study area may be incomplete (Figure 1.1) in areas with no imagery. Despite this the landslides mapped still provide a representative distribution of the impacts of the storm.

The rain radar data used in this study has provided an opportunity to develop a new approach in terms of quantifying rainfall totals for landslide initiation. Despite this the scale at which radar data is collected is on a much broader scale (kilometres) compared to the landslide features mapped. Extracting accurate rainfall values, therefore, remains unfeasible. However, contouring this rain radar data allows for a more representative rainfall distribution while maintaining the overall pattern of rainfall. This allowed for a quantitative rainfall value to be extracted for each landslide and used for analysis of the landslide distribution.

Analysis undertaken on landslides within the detailed study window has been limited to the sizes of landslide source areas and deposits. Future analysis could investigate the relationship between landslide source area sizes and run out distance to see if any correlation exists but was outside the scope of this study. In addition, the source location and catchment order in which debris flows initiated and terminated could be examined to explore where debris flows may initiate and how far downstream they could travel in future events. The estimated volume of material eroded from the storm could be better constrained by field mapping and measurements and would improve calculations of the volume of sediment generated by the storm event.

6.0 CONCLUSIONS

The Tasman Tempest rainfall event was a significant rainstorm triggering thousands of landslides in the southeast Auckland region. With the exception of a small section of coast line, a broad correlation between maximum rainfall and landslide density was observed indicating that the majority landslides were triggered in areas that received 180–200mm of rainfall.

Landslides were predominantly triggered on hill slopes with slope angles of 20–40° underlain by greywacke, which reflected the dominant rock type in the study area. The highest frequency of landslides was observed on pasture as expected, however the highest landslide density was within forest plantations. The “forest plantation” category does not differentiate between recently logged and established pine plantations, and it is probable that most of the landslides occurred in recently logged areas. This was confirmed with the recent aerial photography from LINZ.

Rainfall of 100–120 mm over 24 hours was sufficient to trigger landslides across the region in a variety of land cover types. Rainfall of 140–180 mm over 24 hours was sufficient to cause debris flows to initiate in forest plantations and native forest which is an indication of the Hunua Ranges susceptibility to landslides in high intensity rainfall events. Future events of similar magnitude or larger could be capable of causing damage of similar or greater extent.

Mapping of landslide source areas and deposits show that on average the landslide deposits were larger in size. This can be explained by the occurrence of debris flows which travelled large distances downslope and into the channel network, dispersing and depositing debris over a larger area. Further analysis within the study window considering source locations, slope angle and geology would reveal more characteristics of the landslides and debris flows which were triggered, ultimately giving insight for future rainfall events and the impact they may have.

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8.0 REFERENCES

Basher L. 2010. Storm damage in the Tapawera area during the storm of 16 May 2010. Located at: Landcare Research, Lincoln, New Zealand. 17 p.

GeoNet. 2017. Autumn landslide roundup. Lower Hutt (NZ): GNS Science; [accessed 2021 Mar]. https://www.geonet.org.nz/news/6wxUR4vrA4kgsAgSOWgOiW

Massey CI, Townsend DB, Dellow GD, Lukovic B, Rosser BJ, Archibald, GC, Villeneuve M, Davidson J, Jones KE, Morgenstern R, et al. 2018. Kaikoura Earthquake Short-Term Project: landslide inventory and landslide dam assessments. Lower Hutt (NZ): GNS Science. 45 p. (GNS Science report; 2018/19). doi:10.21420/G2FP82

Noll B. 2017. The Tasman Tempest takes its toll – time to tally up. Wellington (NZ): National Institute of Water and Atmospheric Research (NIWA); [accessed 2018 Dec 4]. https://www.niwa.co.nz/news/the-tasman-tempest-takes-its-toll-time-to-tally-up.

NIWA. 2017.New Zealand climate summary: March 2017. Wellington (NZ): NIWA National Climate Centre; [accessed 2018 Dec 4]. https://www.niwa.co.nz/climate/monthly/climate-summary-for-march-2017.

NIWA High Intensity Rainfall Design System V4. 2017. Wellington (NZ): National Institute of Water and Atmospheric Research (NIWA); [accessed 2018 Dec 11]. https://hirds.niwa.co.nz/search

Page MJ, Langridge RM, Stevens GJ, Jones KE. 2012. The December 2011 debris flows in the Pohara-Ligar Bay area, Golden Bay: causes, distribution, future risks and mitigation options. Lower Hutt (NZ): GNS Science. 91 p. Consultancy Report 2012/305. Prepared for Tasman District Council.

Page MJ. 2013. Landslides and debris flows caused by the 15-17 June 2013 rain storm in the Marahau-Motueka area, and the fatal landslide at Otuwhero Inlet. Lower Hutt (NZ): GNS Science. 35 p. (GNS Science report; 2013/44).

Pain CF. 1968. Geomorphic effects of floods in the Orere river catchment, eastern Hunua ranges. *Journal of Hydrology (New Zealand)*. 7(2):62-74.

Phillips C, Marden M, Basher L. 2012. Plantation forest harvesting and landscape response - what we know and what we need to know. *New Zealand Journal of Forestry*. 56(4):4-12.

Selby MJ. 1976. Slope erosion due to extreme rainfall: a case study from New Zealand. *Geografiska Annaler Series A, Physical Geography*. 58(3):131-138. doi:10.2307/520925.

Watercare 2017. Scale of Tasman Tempest devastation revealed. c2017. Auckland (NZ): Watercare; [accessed 2018 Dec 4]. https://www.watercare.co.nz/About-us/News-media/Scale-of-Tasman-Tempest-devastation-revealed.

Watercare. 2018. Dams. Auckland (NZ): Watercare [accessed 2018 Dec 4] https://www.watercare.co.nz/Water-and-wastewater/Where-your-water-comes-from/Dams.

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