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Slope Failure Susceptibility Assessment

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Hutt City Council District Plan Review

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This report ('**Report**') has been prepared by WSP exclusively for Hutt City Council ('**Client**') in relation to the assessment of slope failure susceptibility in the Hutt City district ('**Purpose**') and in accordance with the Short Form Agreement with the Client dated 18 February 2021. The findings in this Report are based on and are subject to the assumptions specified in the Report and the Service Proposal dated 29 January 2021. WSP accepts no liability whatsoever for any reliance on or use of this Report, in whole or in part, for any use or purpose other than the Purpose or any use or reliance on the Report by any third party.

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Executive Summary

The Hutt City district includes significant areas of steep hilly terrain that are prone to slope failure. Hutt City Council is looking to review and update its District Plan, including Council's approach to slope stability management. WSP has been commissioned by the Council to undertake a technical assessment of slope failure susceptibility across the district as part of this review. The objective is to enhance understanding of slope failure susceptibility in the Hutt City district, in order to inform Council decisions on controls on development, to ensure that development activities do not exacerbate or are not impacted by these hazards. This will also provide a basis for land use planning. This study represents a district-wide appraisal of slope failure susceptibility.

The geology, geomorphology and characteristic mechanisms of landsliding across the district are described, based on the results of a literature review of available information. Factors that influence slope stability are identified from the results of the literature review, including correlation to an inventory of previous landslides collated from Council and WSP records.

Assessment of the slope failure susceptibility is based on weighting of the influencing factors and combining these in GIS using available geospatial datasets. Five categories of slope failure susceptibility are described, from Very Low to Very High. Characteristic slope morphologies within each slope failure susceptibility class are described, and these are mapped across the district in GIS showing the spatial distribution and extent of the different susceptibility categories. The maps should be used at appropriate scales suggested, and where made available to the public through the Council GIS portal, the scale should be restricted.

Suggestions for giving effect to the study in the District Plan are provided and include developing controls for subdivision and buildings, controlling earthworks and vegetation clearance, geotechnical assessments of stability and mitigation measures, provision of hazard and landslide inventory information as part of the LIM process, and consideration of regression and runout areas which could also be impacted by the failure of steep slopes. It is also proposed that the maps be used in future land use planning, urban growth strategies and plan change proposals and could also be useful for the Council's infrastructure departments to understand the resilience of the services provided and for planning for civil defence emergency response.

Recommendations for follow on actions and future enhancements are also included.

1 Introduction

Hutt City Council ('the Council') is currently undertaking a full review of its District Plan, which includes a review of the District Plan's approach to managing slope instability. The Council is seeking to identify areas within the Hutt City district that are susceptible to slope failure, and the most appropriate measures to control the impact of land use, subdivision and development on slope stability.

WSP has been commissioned by the Council to carry out an assessment of slope failure susceptibility within the Hutt City district. This assessment will be used to inform the Council on areas that may warrant particular controls in the District Plan, in order to best manage slope stability issues in relation to land use planning and development.

The Council have requested an assessment of slope failure susceptibility for the Hutt City district, see Figure 1. This report details our methodology, which included a desk study and landslide susceptibility mapping. It provides an appraisal of the stability issues in the Hutt City district, and recommendations for measures to manage the effects of land instability hazards.

2 Study area description

2.1 Geomorphology

The Hutt City district comprises a combination of steep hill terrain, low-lying alluvial valleys and basins, and coastal landscapes (Boffa Miskell, 2012).

Several areas of hill terrain bound and divide the valleys within the Hutt City district. These areas typically comprise broad hilltops between deeply incised hillslopes and gullies, with slope angles often greater than 30 degrees. The Western and Eastern Hutt Hills rise to about 450 m above sea level on either side of Hutt Valley. Several suburbs are located in these hills, with the slopes having been modified for residential development with cuts, fills and retaining walls.

The Remutaka Ranges, which occupy the eastern side of the district, rise to about 900 m above sea level and are largely undeveloped. These ranges are an area of rapid uplift and erosion due to tectonic activity. Vegetation cover in the areas of hill terrain typically comprises regenerating native forest and scrub, with smaller patches of mature native and exotic vegetation.

Ridge-top areas in the Western Hutt Hills are frequently flat or gently rolling, in contrast with the surrounding steep hillslopes and sharp ridges seen elsewhere in the Wellington Region. These areas, known as the K-surface, represent an old flat-lying surface that has been uplifted by fault activity and subsequently subject to extensive weathering and dissection by stream gullies. Large parts of the Western Hutt Hills suburbs are located on these broad hilltops

The main valley in the Hutt City district is Hutt Valley, which extends southwest to northeast from the harbourfront at Petone to the northern extent of the district at Taitā Gorge. Secondary valleys include Stokes Valley, which connects to Hutt Valley at Taitā Gorge, and Wainuiomata Valley, which meets Cook Strait at the south coast.

Coastal geomorphology is highly varied in the Hutt City district. Steep bedrock cliffs, sometimes in excess of 200 m high, are present in places, particularly on the south coast. Gently sloping beach and dune environments can be found in the Petone and Eastern Bays harbourfront areas, as well as to the south of Pencarrow Head and Wainuiomata Coast.

Figure 1: The Hutt City district.

2.2 Geology

The regional geology of the Hutt City district is described in the 1:50,000 and 1:250,000 GNS geological maps of the Wellington area (Begg & Mazengarb, 1996; 2000). These maps indicate that the bedrock underlying the district is Triassic Age Rakaia terrane, also known as Wellington Greywacke, with overlying Quaternary superficial deposits.

Wellington Greywacke comprises interbedded sandstone and argillite rock that is generally highly fractured and sheared due to the regional tectonic activity. The hill terrain in the Hutt City district is primarily formed from uplifted greywacke materials which have subsequently been eroded.

The greywacke hillslopes are overlain by variable thicknesses of superficial deposits including colluvium, alluvium, loess, and topsoil. These overlying deposits are typically less than 2 m thick but increase in thickness towards the base of slopes and in gully floors, where fan and slip deposits generally accumulate. In the hilltop K-surface areas, extensive weathering has led to greater thicknesses of soil including loess and topsoil.

The Lower Hutt valley floor is underlain predominantly by alluvial sands and gravels, along with fan deposits and some marine sediments. In Wainuiomata, the valley floor also comprises alluvial sands and gravels and fan deposits, and old lake and swamp deposits.

In the coastal areas of Petone and the Eastern Bays, there are beach deposits comprising marine gravels with sand and mud, while landslides from steep coastal greywacke cliffs have deposited fan and scree debris at the base of the slopes.

2.3 Seismicity

The Hutt City district is an area of significant seismicity. The New Zealand Active Faults Database from GNS (https://data.gns.cri.nz/af/, 1:250,000 scale) shows that four active faults fall within the Hutt City district, including the Wellington Fault that runs through the urban areas of the district, see Figure 1. These faults are summarised in Table 1.

Table 1: Summary of active faults within the Hutt City district.

Fault name	Estimated magnitude	Recurrence interval (yrs)
Wellington Fault	7.6	500 to 1000
Whitemans Valley Fault	7.0	>10,000 to ≤20,000
Wairarapa Fault	8.2	1150 to 1200
Baring Head Fault	Unknown	Unknown

The Wellington Fault trends northeast to southwest along the western boundary of Hutt Valley, close to the location of Te Awakairangi / Hutt River. The Wellington-Hutt Valley segment of the Wellington Fault has the potential to cause earthquakes and associated significant ground shaking within the Hutt City district and could produce metre-scale surface rupture displacements (Saunders, et al., 2016).

There is also potential for significant ground shaking within the Hutt City district resulting from earthquakes associated with the other faults in the district as well as those located elsewhere in New Zealand, or from the Hikurangi subduction zone to the east of the North Island.

3 Desk study

3.1 Factors influencing slope stability

The susceptibility of a slope to instability is dependent on a combination of factors, which can be divided into controlling factors and triggering factors (Kritikos & Davies, 2015). Inherent geological and geomorphological conditions, such as slope angle or lithology, can predispose a slope to failure (McColl, 2015), while preparatory factors, like weathering or the removal of vegetation, can increase the susceptibility of the slope to failure over time (Crozier & Glade, 2005). Approximately 90% of landslides are triggered by a rainfall event (NIWA, et al., 2012), with seismic shaking being the second most common trigger in New Zealand (Saunders, et al., 2016). Landslides may also be initiated by alternative geomorphological, physical or human triggers, as outlined by McColl (2015).

Kritikos and Davies (2015) provide an overview of ten factors influencing slope failure susceptibility, for which data are available in New Zealand. These factors are:

1. Slope angle
2. Lithology
3. Land cover (vegetation)
4. Soil drainage
5. Soil induration (soil hardness)
6. Proximity to faults
7. Proximity to streams
8. Slope aspect
9. Curvature
10. Rainfall intensity

3.2 Influence of human activity

Anthropogenic modification of slopes, through activities including farming, forestry or urban development, can have a negative effect on slope stability. An overview of these various anthropogenic factors is provided by McColl (2015). Brabhaharan et al. (1994) mapped slope modification within the Hutt Valley area during their study of earthquake induced slope failure hazards, and highlighted the importance of three anthropogenic factors in particular for the Hutt Valley area:

1. Filling of gullies with poorly compacted materials;
2. Excavation, cutting and over-steepening of slopes when building infrastructure; and
3. Poor stormwater or wastewater drainage allowing uncontrolled flow onto slopes.

One example illustrating the influence of human activity on landslide occurrence is the 7 August 2006 slip in Kelson that occurred during heavy rain (about 52 mm in 48 hours). As summarised in a GNS reconnaissance report (Hancox, et al., 2007), the slip involved a large fill that had been constructed 40 years prior at the head of a gully without first removing underlying vegetation. This vegetation subsequently decayed and formed a weakened surface on which the fill eventually slipped. A sewer pipe ruptured in the initial failure and discharged wastewater onto the exposed slip area, causing additional slippage that undermined a house which ultimately had to be demolished.

Anthropogenic modification could also have a positive effect on slope stability, where cuts and fills are formed to gentler slopes or through the adoption of engineering measures.

3.3 Rainfall-induced landslides

Rainfall is the most significant trigger of landslides, with about 90% of landslide failures linked to a period of intense precipitation (NIWA, et al., 2012). Rainfall can cause changes to groundwater conditions within a slope, such as increasing pore water pressures, inducing water flow within a slope, and saturating slope materials (increasing slope mass), all of which can negatively affect slope stability (McColl, 2015). Considering this, prolonged and/or intense rainfall therefore increases the potential for slope failures.

Several studies within the past 50 years have reported on rainfall-induced landslides in the Wellington Region. These investigations have generally followed significant rainstorm and landslide events, including in Winter 1974 (Eyles, et al., 1978), December 1976 (Wellington Regional Water Board, 1977; McConchie, 1977; Riddolls, 1977; Eyles, et al., 1978), August 1994 (Perrin & Beetham, 1994), February and August 2004 (Hancox & Wright, 2005; Ian R Brown Associates, 2005), July 2006 (Hancox, et al., 2007), June to August 2008 (Hancox & Nelis, 2009), and May 2015 (Page & Rosser, 2015). A more extensive list of significant historical storm events affecting the Hutt City district is provided in Appendix B.

The future influence of climate change on rainfall-induced landslide occurrence is complex. It is generally accepted, however, that total rainfall will increase in western New Zealand, and storm frequency and intensity will increase throughout the country, which are expected to lead to increased landslide occurrence (MfE, 2008). The effect of a changing climate could be obscured by the effect of changing human activity on landslide occurrence (Crozier, 2010).

3.4 Earthquake-induced landslides

Strong earthquake shaking can cause landslides by inducing elevated shear stresses and increased pore water pressures, which make a slope more susceptible to failure (McColl, 2015).

A study of earthquake-induced slope failure susceptibility in the Hutt Valley area was completed by WSP (as Works Consultancy Services) in 1994 (Brabhaharan, et al., 1994). Susceptibility maps were prepared at 1:25,000 scale based on datasets for slope angle, slope height, slope modification, geology, groundwater, and past landslides. It was reported in this study that most historical earthquake-induced landsliding in bedrock occurred on slopes greater than 30°, road and railway line cuttings, and areas of oversteepening by river erosion. Failures in alluvial materials generally occurred along river channels, terraces and coastal cliffs. The most extensive earthquake-induced landsliding in the Wellington Region in the last 175 years was caused by the M8.2 Wairarapa earthquake in 1855, and few other earthquakes have caused landslides in this region.

In some cases, seismic shaking can weaken slopes without causing failure. There is then a greater probability of failure during a subsequent earthquake or storm event. This effect has been observed in Kaikōura (Mason, et al., 2018) and overseas (Lin, et al., 2006). On 15 November 2016, the day after the M7.8 Kaikōura earthquake, 94.2 mm of rain was recorded in the Lower Hutt catchment, and thirty landslides were recorded by the Council; the largest number of landslides on a single day in the period 2004 – 2020 (Christison, 2020).

Earthquake ground motions can be amplified in areas of topographic relief. This effect was investigated by Kaiser et al. (2014) for the Port Hills area during two earthquakes in the Canterbury earthquake sequence of 2010 – 2011, with topographic amplification often observed at ridge-top locations. A similar study investigated the response of selected hillslopes in Wellington to earthquake shaking (Janku, 2017), which showed that topographic amplification could occur in areas of hilly terrain within the Hutt City district.

3.5 Historic landslides in the Hutt City district

Hutt City Council holds records of reported slips in the district, and these records were analysed along with data from the GNS Science's New Zealand Landslide Database (NZLD) by Katie Christison, a summer student intern with the Council (Christison, 2020). The majority of the Hutt City records were along road corridors, where the Council would have had to respond to these landslide events. For the period 2004 – 2020 (the period covered by the operative District Plan), Christison analysed a database of 571 dated landslides to correlate their occurrence with daily rainfall records. Of these 571 landslides, 346 occurred in the Western Hutt Hills, 83 occurred in the Eastern Bays, 22 occurred in Stokes Valley, and 120 occurred in other suburbs.

GNS maintains the New Zealand Landslide Database (NZLD; https://data.gns.cri.nz/landslides/), which holds data on landslides from across the country. Some landslides were identified during reconnaissance mapping undertaken by GNS following storm events, including in 1994, 2004, 2006, 2008 and 2015. Other landslides have been inferred from aerial imagery or various media sources. 262 landslides from the NZLD are located within the Hutt City district, but only 23 records have an associated date of occurrence.

Ian R Brown Associates (2005) located 113 landslides across the district during their investigation following significant storms in 2004. This inventory included 40 Council records from 2004, 13 EQC claims relating to landslip damage, and other landslides identified during an aerial mapping flight undertaken in January 2005. The majority of landslides mapped in the Eastbourne area were reported to have occurred on slopes of at least 40°.

A major storm on 20 December 1976 caused hundreds of landslides in Wellington City and Hutt Valley. Mapping indicated that the highest density of landsliding occurred in the Western Hutt Hills and Stokes Valley (Wellington Regional Water Board, 1977). Hufschmidt & Crozier (2008) completed an analysis of aerial photographs taken after the 1976 storm and identified 792 landslides in the Western Hutt Hills. McConchie (1977) mapped 78 landslides in Stokes Valley and reported that all slips occurred on slopes of at least 19°. Riddolls (1977) reported that the majority of the slips in the Western Hutt Hills occurred on slopes of at least 25°.

Christison has mapped 571 landslides from internal Hutt records and from the GNS landslide database. It would be valuable to map the other landslide records available into a GIS database so that these could be held by the Council to inform hazards in the district.

3.6 Typical failure mechanisms

The typical mechanisms by which slope failure occurs in the Hutt City district are rock falls, rock slides, soil slides, and debris flows. Slumping can also occur, mostly in areas of fill associated with the development of residential areas and transport routes.

Rock falls and rock slides commonly occur from steep greywacke slopes, particularly where these are modified by road or residential cuttings. The stability of these bedrock materials is highly dependent on the presence of defects (joints, crushed and shear zones, and clay gouges). If defects are closely spaced, persistent through the rock mass, and dipping out of the slope, then failure susceptibility tends to be higher.

Shallow soil slides are common in the surficial regolith materials overlying greywacke bedrock, particularly if a slope is bare or lightly vegetated. These shallow failures can extend into debris flows if sufficient water is present to fluidise the slip debris, during large storms for example. Runout distances of debris flows can be significant, particularly if they become channelised.

Localised geological conditions and terrain as well as the trigger events (eg earthquake or storm) generally determine which of these failure mechanisms occurs, while slope modification can also increase the likelihood of some failure mechanisms. Some landslides may exhibit characteristics of two or more failure mechanisms. These typical failure mechanisms are summarised with examples in Appendix C.

4 Study methodology

The aim of this study is to enhance understanding of slope failure susceptibility in the Hutt City district, in order to provide a basis for updated land use planning and to inform Council decisions on controls on development, to ensure that development activities don't exacerbate or be affected by these hazards. In order to meet this aim, factors that influence slope stability are identified and combined to form a map of slope failure susceptibility.

The term 'slope failure' is used equivalently with 'landslide' in this report, and includes all types of failures in slopes, including the mechanisms discussed earlier in this report. For the purposes of this study, failures caused by liquefaction and associated lateral spreading in the relatively flat areas of the district are excluded from the mapping we present, because such hazards are not classified as landslides and are considered separately.

This methodology is based on international guidelines developed by the JTC-1 Joint Technical Committee of Landslides and Engineered Slopes (Fell, et al., 2008), who define key landslide mapping terms as shown in Table 2.

Table 2: Key landslide susceptibility mapping terminology.

Term	Definition
Landslide	The movement of a mass of rock, debris, or earth soil down a slope.
Landslide inventory	An inventory of the location, classification volume, activity, date of occurrence and other characteristics of landslides in an area.
Landslide susceptibility	A quantitative or qualitative assessment of the classification, volume (or area), and spatial distribution of landslides which exist or potentially may occur in an area. Susceptibility may also include a description of the velocity and intensity of the existing or potential landsliding. Although it is expected that landsliding will occur more frequently in the most susceptible areas, in the susceptibility analysis, time frame is explicitly not taken into account.
Zoning	The division of land into homogeneous areas or domains and their ranking according to degrees of actual or potential landslide susceptibility, hazard or risk or applicability of certain hazard-related regulations.

The following steps describe the methodology developed and used in this study:

1 Identify key areas within the study area

Greater refinement of mapped slope failure susceptibility zones has been applied in key areas of existing and potential future development (see outlined areas in Figure 1). These areas were selected by the Council from activity areas within the operative District Plan. The key activity areas are:

- Hill Residential Activity Area;
- Landscape Protection Activity Area;
- General Residential Activity Area (in the hill suburbs);
- Rural Residential Activity Area;

Activity areas outside of those listed above are generally much less developed, and the same level of refinement to mapped slope failure susceptibility is not necessary and a lower level would be acceptable. This includes areas zoned within the General Rural and General Recreation Activity Areas, such the Remutaka Forest Park, the Belmont and East Harbour Regional Parks, and the Wainuiomata Water Collection Area.

2 Identify the geology and geomorphology of the study area

This process involved a desk study of geology maps, a review of relevant past investigations and literature, and an examination of stereo aerial photographs.

3 Identify past slope failures

Past landslides were identified and captured onto a GIS[1] platform during the desk study stage. This landslide inventory comprised data provided by the Council, along with areas of slope instability recorded in the New Zealand Landslide Database (NZLD) collated by GNS Science. All landslides were mapped as point locations.

4 Collect data on factors that influence slope failure susceptibility

Based on similar past studies and WSP's knowledge of the study area, a series of factors that influence slope failure susceptibility in the Hutt City district were identified during the desk study. These factors, summarised in Table 3, were captured onto the GIS platform, allowing their spatial distribution and extent to be visualised.

Table 3: Factors affecting slope failure susceptibility and the associated data sources.

Factor	Influence on slope failure susceptibility	Data source
Slope angle	The steeper the slope, the more susceptible it is to failure. A greater slope angle increases the stress acting on the slope due to gravity.	HCC and GWRC Created from a Digital Elevation Model (DEM) with a 1 m cell size. Urban areas: DEM processed from HCC 2016 LiDAR[2] data. Rural areas: DEM processed from GWRC/WAGGIS 2013 LiDAR data.
Slope aspect	The compass direction in which a slope faces can influence its exposure to sun as well as prevailing wind and rainfall. These can directly influence the slope stability or indirectly influence the vegetation cover.	HCC and GWRC Created from 1 m DEM.
Lithology	Related to the shear strength and permeability of the slope materials, which influence the vulnerability of the slope to erosion and weathering. Slopes with defects (bedding, joints etc.) dipping downslope are generally more susceptible to failure.	GNS (Begg & Mazengarb, 1996) Geology of the Wellington area, 1:50,000 scale
Land cover	Influences surface water runoff, infiltration, and erosion, with sparsely vegetated slopes generally more susceptible to instability. The presence of root systems can also improve stability.	Manaaki Whenua Land Cover Database (LCDB), version 5.0.
Distance to active fault	Slopes located close to or within fault zones are likely to be weakened due to the shearing, crushing and shaking associated with fault movement, and can experience greater ground motions during earthquakes associated with these faults.	GNS NZ Active Fault Database, 1:250,000 scale.
Distance to stream	Slopes located close to streams may be undercut and destabilised by river erosion at the toe of the slope.	LINZ Topo50 NZ River Centre lines, 1:50,000 scale.

[1] Geographic Information System, a mapping system to manage and analyse spatial data. In this study, ArcGIS software was used.
[2] Light Detection and Ranging, a remote sensing method that uses lasers to measure the earth's surface.

Factor	Influence on slope failure susceptibility	Data source
Soil drainage	Slopes that drain slowly are more likely to experience elevated pore water pressures, which tends to decrease slope stability.	Ministry for the Environment Land Environments of NZ (LENZ), Level 4 polygons.
Soil induration (hardness)	Less indurated soils are more susceptible to erosion and instability than strongly indurated soils.	Ministry for the Environment Land Environments of NZ (LENZ), Level 4 polygons.
Slope curvature	The curvature (convex, flat, or concave) of a slope influences the flow of water across it and concentration of flows, which can in turn influence slope stability.	HCC and GWRC Created from 1 m DEM.

Each factor dataset was divided into categories, with each category assigned a numeric value. Higher values were assigned to the categories associated with greater slope failure susceptibility. For example, steeper slopes were given a larger value than shallower slopes.

The slope angle, slope aspect and slope curvature factor datasets have been processed from a DEM derived from a combination of 2013 and 2016 LiDAR data. The 2016 LiDAR data covers only the urban areas of the district, but is of higher quality than the 2013 LiDAR data which covers the full district.

The factors chosen for this study, as listed in Table 3, have been chosen as they are considered to be important controls on slope stability in the Hutt City region. Data relating to triggering factors, such as rainfall depth/duration and earthquake ground shaking intensity, are not included.

5 Select size of mapping unit

The factor datasets are divided into gridded maps using the GIS platform. There are multiple options available for dividing the factor datasets into grid cells, and different sizes of cells can be chosen. The simplest and most common approach is to use square grid cells. For an image, these cells are known as pixels. For this study, the factor dataset maps are prepared using a 1 m by 1 m pixel size. High-resolution LiDAR-derived datasets are used for some of the factors, so a 1 m by 1 m pixel size allows localised topographic variations (such as small cut and fill slopes) to be captured in the susceptibility mapping.

6 Assess correlation between landslide occurrence and influencing factors

The correlation between the mapped landslides and each of the influencing factors was analysed to assess the relative importance of each factor for landslide occurrence. This assessment allowed relative weightings to be determined for each factor dataset.

Various quantitative methods may be used to assess the statistical relationship between landslide occurrence and the influencing factors. These methods generally require the use of a landslide inventory to train and test the model of susceptibility that is produced, meaning the predictive capability of the model is strongly dependent on the quality of the data.

The landslide inventory compiled for this study comprises primarily point locations for individual slips, and there are inaccuracies in the location of some of these points. Some are located at the true site of the slip, while others are located within the associated property address, or on the road adjacent to a cut slope where the failure occurred, for example.

A quantitative approach using the Frequency Ratio method was trialled, but we found the landslide point locations to be insufficient for assessing the importance of each influencing factor for landslide occurrence.

A qualitative approach was determined to be the most appropriate method given the constraints of this study. This approach involved overlaying accurately located past slope failures onto each factor dataset map to observe where landslides typically occur, and applying expert judgement to decide upon the relative importance of each factor.

Weightings for each influencing factor were assigned based on the assessed relative importance of each factor, with weighting values derived using an analytical hierarchy process. Slope angle was considered to be the most important factor, followed by geology and land cover. The remaining factors were considered to be less important and were assigned lower weightings.

7 Combine factors to determine slope failure susceptibility

Having determined the relative importance and weighting of each factor, the mapped individual factors were combined in the GIS platform to calculate slope failure susceptibility ratings across the Hutt City district. These ratings were then classified into five categories to represent Very Low, Low, Moderate, High and Very High slope failure susceptibility.

8 Validate model

Various checks were undertaken to validate the landslide susceptibility map. These checks comprised:

- Overlaying points from the landslide inventory and determining whether the modelled susceptibilities correctly reflect past slope failure locations.
- Testing different slope combinations to check that the modelled landslide susceptibilities realistically reflect expected slope failure susceptibility relationships. For example, a 35° greywacke slope should typically have a lower susceptibility than a 35° alluvium slope, and a 45° forested slope should typically have a lower susceptibility than a 45° bare slope.
- Undertaking site observations at various individual sites within the identified key activity areas, to check that modelled landslide susceptibilities accurately reflect on-site assessments of susceptibility.

9 Refine model in key areas

In the key Activity Areas identified by the Council, the landslide susceptibility model map was refined to remove noisy artefacts and group common areas of slope failure susceptibility, to produce more realistic zones. This process involved eliminating some features where the modelled susceptibility was judged to have been overestimated compared to reality, including the Hutt River stopbanks and bridge approach embankments, that are not important for the purpose of this study. Hillshade and slope angle maps, produced from digital elevation data, were used in this refinement process.

10 Recommend planning policies and rules to ensure future development avoids or mitigates potential slope instability.

This report makes recommendations for giving effect to the findings of this study into the Hutt City Council District Plan.

11 Present maps

Slope failure susceptibility maps for the Hutt City district are presented at 1:25,000 scale in Appendix A.

5 Slope Failure Susceptibility Assessment

5.1 Very High and High susceptibility

Zones of very high and high slope failure susceptibility consist primarily of very steep land, and areas where there is known past slope instability. Any slope greater than 50° has been classified as having a very high slope failure susceptibility, and most slopes greater than 45° are also captured in these zones. These very steep slopes are predominantly located in areas of greywacke bedrock. Where weaker materials such as alluvium, colluvium and K-surface cover beds (loess and soil) are mapped as the underlying geology, slopes greater than 35° generally fall into the very high and high susceptibility zones, due to the lower strength of these materials.

Some typical slope morphologies that are associated with these zones are summarised below.

5.1.1 Eroded Wellington Fault scarp

These greywacke slopes bounding the western side of the Hutt Valley are generally very steep, and have been steepened in places by formation of road cuttings (Figure 2). The slopes are underlain by fault-disturbed or highly fractured rock due to their close proximity to the Wellington Fault, resulting in high susceptibility to failure. The proximity of the fault would also expose them to strong ground shaking and topographic amplification effects in the event of a localised fault rupture.

Figure 2: The steep eroded scarp of the Wellington Fault running parallel to State Highway 2.

5.1.2 Large steep gullies and coastal cliffs

Typical stable angles for natural slopes in moderately to highly weathered Wellington greywacke are around 38-43°, but slope angles of 50° or greater are observed in less weathered rock without moderately steep unfavourable defects, or near the base of large gullies and at coastal cliffs. These slopes are often naturally over steepened by stream undercutting or wave action. Large, very steep slopes such as these are considered to be very highly susceptible to failure due to significant earthquakes or storms. See Figure 3.

It should be noted that the stable angle of individual greywacke slopes is highly dependent on the degree of weathering and the extent and intensity of fracturing in the bedrock, as well as the presence, persistence and orientation of dominant defects with respect to the overall slope.

Figure 3: Korokoro Stream gully, with very steep greywacke slopes.

5.1.3 Road cuttings

These slopes can be high and very steep, particularly those of older age (Figure 4). The primary access routes into the early hill suburbs of Belmont, Harbour View, Korokoro and Normandale are via roads with steep cut slopes that have a history of frequent slope instability. The slopes adjacent to Wainuiomata Hill Road, initially constructed in the mid-1800s and further developed in the 1950s, also have several recorded instances of slope failure.

Many smaller residential streets in the hill terrain areas of Hutt City district also feature steep road cuttings that are susceptible to slope failure, as indicated by the landslide inventory compiled for this study.

Steep and high cut slopes are also found in the Belmont and Dry Creek quarries. These slopes are also considered to be very highly susceptible to failure.

Figure 4: Korokoro Road, with steep cut slopes to the right of the road, and houses positioned behind the crest of these slopes. (Image from Google Maps Street View).

5.1.4 Residential cut and fill slopes

In the hill suburbs of the Hutt City district, slopes are often modified to form flat building platforms (Figure 5). This process has typically involved the formation of cuts in bedrock slopes, and the downslope placement of fill material to create level ground with steepened edges. Cuttings are generally steeper than natural greywacke slope angles and are susceptible to rock falls and slides if left unsupported. The placement of fill materials can overload natural slopes and increase the failure susceptibility of the underlying bedrock. Where fill slopes are poorly constructed, there is potential for significant failures within the fill material, like that which occurred in Kelson in 2006.

The slope failure susceptibility of residential cuts and fills may be reduced by the implementation of retaining measures including retaining walls, soil nails, rock anchors, and shotcrete, and by good stormwater drainage design and infrastructure. These measures generally exist on a property-specific basis and have not been mapped in this study. It should be noted that engineered measures remain susceptible to being overwhelmed in significant trigger events, particularly under strong seismic shaking such as that from a large Wellington Fault earthquake.

Figure 5: Cedar Street, Maungaraki, showing different stages of slope modification for residential development. Note cut slopes behind the house on the right, and in the plot to the left. (Image from Google Maps Street View).

5.1.5 Colluvium-filled bedrock depressions

Colluvium-filled bedrock depressions (CBDs) originate as natural gully-like depressions cut through the surficial soils overlaid on greywacke slopes in the Wellington region (Crozier, et al., 1990). These depressions represent drainage convergence points and over time can become infilled by soil and debris, with this fill often being fairly loosely compacted. CBDs may be difficult to distinguish from surrounding greywacke slopes once infilled, due to their lack of topographic expression. Once the colluvium in a CBD reaches a critical thickness, they are very susceptible to failures, particularly when groundwater levels are elevated in periods of heavy or prolonged rainfall. With many slopes having been deforested in the past 150 years during anthropogenic development, there has been a loss of root support for these CBDs, meaning they are now more susceptible to failure.

Given the lack of topographic expression of CBDs, these features are generally not identifiable in the slope angle maps used for this study. The regional scale geology maps used have also not differentiated CBDs from greywacke bedrock materials. Therefore, it is likely that many CBDs are not captured in our slope failure susceptibility mapping. These features may be identified by undertaking site-specific slope stability investigations, in which case they should generally be considered to have significant potential for slope failures.

5.2 Moderate susceptibility

Zones of moderate slope failure susceptibility generally comprise moderately steep to steep greywacke slopes, typically in the range of 35° to 45°. Shallower slopes of around 25° to 35° in weaker materials also fall within this zone, but may be more susceptible to slope failure in places depending on the combination of land cover and other influencing factors.

The potential for slope failures in these areas of moderate susceptibility is often highly dependent on site-specific conditions such as the thickness of surficial soils such as loess and colluvium, the degree of bedrock weathering, and the orientation of rock defects. Given the district-wide nature of this study, these site-specific conditions are not captured in the susceptibility mapping.

Some typical slope morphologies that are associated with this zone are summarised below.

5.2.1 Fringes of large steep gullies

While steep to very steep greywacke slopes are often present in large gullies in the Hutt City district, slopes at the upper and outer margins of these gullies are generally more rounded and shallower (Figure 6), so have a lower failure susceptibility. These areas are also not subject to significant stream undercutting like the slopes deeper in gullies. Vegetation coverage is also likely to be denser due to the shallower slope angles, with the roots of trees and scrub often providing a stabilising effect.

Figure 6: View over Korokoro Stream gully, with residential development on the rounded hillslopes adjacent to the steeper gully slopes.

5.2.2 Smaller gullies

Shallow and/or broad gullies are likely to have gentle to moderately steep slope angles and generally support a lesser water flow compared to larger, steeper gullies. These gullies are typically less susceptible to slope failures, but this susceptibility may increase over time as ongoing stream erosion and weathering undercuts and weakens the gully slopes.

5.2.3 Smaller residential cut and fill slopes

In areas of residential development on gently dipping land, or where there is a lower density of development, some slopes have only been subject to minor modification in order to construct level building platforms. See examples within the Kelson subdivision shown in Figure 7. Cut and fill slopes that are shallower in angle and smaller in height have a lower slope failure susceptibility than those which are steeper and/or higher. Given that there is still a potential for slope failure however, slope stability should be addressed if additional development is considered on or close to these slopes.

Figure 7: Slope modification, including some small residential cuts and fills, at a recent subdivision in Kelson. (Photo from Stuff).

5.3 Low and Very Low susceptibility

Zones of Low and Very Low slope failure susceptibility comprise the shallowest slopes and flat areas of the Hutt City district. Any slope shallower than 20° has been classified as having a very low slope failure susceptibility, reflecting reported rainfall-induced landslide thresholds for the wider Wellington Region, which range from 18° to 22° (Eyles, et al., 1978; McConchie, 1980; Crozier, et al., 1990; Page & Rosser, 2015). Some steeper slopes are also captured into these susceptibility zones depending on local conditions, especially slope materials and vegetation cover.

Given the district-wide appraisal undertaken in this study, land classed as having low and very low slope failure susceptibility cannot be confirmed to have no potential for land instability. Site-specific conditions that locally increase slope failure susceptibility may not have been captured at the scale of the mapping completed in this study.

Some typical slope morphologies that are associated with this zone are summarised below.

5.3.1 Valley floors and coastal beaches

The valley floors in the Hutt City district, such as the Hutt Valley (Figure 8), Wainuiomata and Stokes Valley, are generally flat or gently dipping at less than 20°, as are beach areas in Petone, the Eastern Bays, and the south coast. Valley floors and beaches have a very low potential for slope failure, although the formation of cuttings in these areas (e.g. for residential development) would increase the slope failure susceptibility. Beach areas will often be exposed to coastal erosion, but this process is not considered in this study.

Some of these areas may be susceptible to fault rupture or liquefaction-induced ground deformation, but deformation of this form has not been considered in the slope failure susceptibility mapping completed in this study.

Figure 8: The flat floor of Hutt Valley, looking towards the Eastern Hills.

5.3.2 Raised terraces and broad hilltops

Gently sloping elevated areas, which are particularly common within the Western Hutt Hills (Figure 9), are generally considered to have very low and low slope failure susceptibilities, based primarily on their shallow slope angles. These areas are typically underlain old, uplifted alluvial deposits or loess and topsoil in the highly weathered K-surface areas. Where these materials are eroded and steepened, particularly at the fringes of these raised, flattened areas, the potential for slope failure tends to increase.

Figure 9: Broad hilltops in the Western Hutt Hills, characteristic of the K-surface. Several suburbs are located across these hilltop areas.

5.3.3 Greywacke slopes less than 35°

Shallow slopes in greywacke bedrock of less than 35° are generally captured within the low and very low susceptibility zones. The localised presence of significant weathering and unfavourable defect conditions increases the susceptibility of these slopes to failure

5.3.4 Slopes less than 25° in weaker materials

Slopes of less than 25° in weaker materials such as alluvium, colluvium, loess and topsoil are also generally considered to have low and very low failure susceptibilities. This is in agreement with previous studies by GNS' Page and Rosser (2015), who investigated landslides triggered by a storm event affecting the Kāpiti and Hutt Valley areas in May 2015, and reported that only 8% of 333 identified landslides occurred on slopes shallower than 25°. They also noted that almost all landslides occurred on pasture slopes as opposed to those with a woody vegetation cover (forest and scrub).

5.3.5 Engineered slopes in valley floor areas

Some man-made slopes are present in the valley floor areas of the Hutt City district, with the majority of these located in the Hutt Valley and Wainuiomata. Stopbanks alongside the Hutt and Wainuiomata Rivers and bridge abutments on the Hutt Valley floor are moderately steep to steeply sloping in places (Figure 10). However, these slopes are generally engineered and unlikely to fail in the same manner as undisturbed and modified slopes in the hill terrain around the district. Therefore, these slopes have been classed as areas of very low slope failure susceptibility.

Opus (now WSP) have previously completed an earthquake risk assessment for stopbanks alongside the Hutt and Wainuiomata Rivers (Opus, 2005).

Figure 10: Stopbanks to either side of the Hutt River.

5.3.6 Regression and runout from adjacent slopes

Flat or gently sloping land, which has a very low potential for slope failure, may still be affected by landslides. Regression of steep hillslopes, particularly over long time periods, can affect flat land located nearby. This may include clifftop areas, or flat platforms formed using fill material.

Debris inundation and extended runout can also affect land downslope of slope failures. This may include beaches located at the foot of a steep cliff, or land at the mouth of a gully prone to debris flows.

The use of setback distances or buffer zones adjacent to steep and very steep slopes of very high and high slope failure susceptibility would provide some protection against immediate regression and debris inundation, but it would be most appropriate to assess the potential for regression and inundation on a site-specific basis. Longer-term regression and extended debris runout distances are highly variable and have not been considered in this study of slope failure susceptibility.

6 Slope Failure Susceptibility Maps

6.1 Scale of usage for susceptibility zones

This study represents a district-wide appraisal of slope failure susceptibility. International guidelines published by the JTC-1 Joint Technical Committee of Landslides and Engineered Slopes suggest that an appropriate scale range for susceptibility zoning mapping completed across local areas (defined as 10 km^2 to 1000 km^2; Hutt City is 377 km^2) is between 1:25,000 and a maximum of 1:5,000 (Fell, et al., 2008). Based on these guidelines, we recommend that when implemented in the District Plan, zones based on this slope failure susceptibility study are not displayed at scales larger (i.e. in more detail) than 1:5,000. If the zones are to be displayed at larger scales than this, such as for individual properties, then a disclaimer should be included, potentially as overlay text on the map.

6.2 Limitations

6.2.1 Slope modification within individual properties

The mapping within the study area was carried out from examination of remotely sensed data including LiDAR and aerial imagery, along with regional datasets. With this study being completed at a district-wide level, no access was gained to properties, and site-specific stability assessments have not been undertaken. Property owners and developers should seek independent advice on land stability at their particular property, prior to development.

Slope modification within individual properties are not captured beyond that which is captured in the LiDAR and aerial imagery. The capture of slope modification is limited by the quality and age of these datasets. Any modifications post-dating the acquisition of the LiDAR and aerial imagery will not be captured in the susceptibility maps. The actual slope failure susceptibility within individual properties may therefore differ from those presented in this study. Confirmation of susceptibilities within a single property would require more detailed, site-specific information on the subsurface conditions and the efficacy of any existing measures to mitigate instability hazards, which is beyond the scope of this current study.

6.2.2 Data quality

LiDAR data from 2013 and 2016 were used in the susceptibility mapping. The slope angle, slope aspect and slope curvature factor datasets have been processed from a DEM derived from a combination of 2013 and 2016 LiDAR data. The 2016 LiDAR data covers only the urban areas of the district, but is of higher quality than the 2013 LiDAR data which covers the full district. Therefore, there is a difference in quality of the mapped susceptibility zones in the urban areas compared to the rural areas. The higher-quality data covers the majority of the key activity areas selected by the Council (see Figure 1).

The maps of slope failure susceptibility presented in this study should not be regarded as static. The use of updated and/or higher quality datasets and improved mapping of past and existing slope failures can allow the susceptibility zones to be refined. We understand that newly acquired LiDAR data for the district is due to become available in 2021, and recommend that the slope failure susceptibility mapping be updated using this new data once available.

7 Giving Effect to the Project

7.1 The existing District Plan

Chapter 14H of the current District Plan addresses natural hazards including seismic induced hazards, landslides, flood and coastal hazards, and presents the issues, objective and policy, and became operative in 2003/2004. The objective is to avoid or reduce the risk to people and their property. Where areas susceptible to landslides have been identified, appropriate conditions are to be provided to mitigate the adverse effects of subdivision and development on the vulnerability of people and their property. The section states that any proposed subdivision and development in steep areas will be managed to reduce vulnerability from landslide hazards which can be triggered by earthquakes or by excessive rainfall. The steep slopes will be identified as Hill Residential Activity Areas, Landscape Protection Residential Activity Areas and Passive Recreation Activity Areas to provide the necessary conditions of compliance.

The conditions of compliance manage those aspects of proposed subdivision or development which can increase the susceptibility of a slope to landslides. This includes conditions on vegetation clearance, removal of topsoil, excavation, and earthworks. The hazard assessment is to be carried out by an appropriately qualified and experienced person. If an area is identified as being susceptible to slope failure, slope stabilisation and appropriate building setbacks must be implemented in line with the requirements of the New Zealand Building Code, before development can occur. The actual rules to manage the risks are provided in Chapter 11 on Subdivision and Chapter 14I on Earthworks.

Chapter 14I on earthworks focuses on the natural character, and managing earthworks to protect significant escarpments, steep hillside areas, and the coastal area by ensuring that earthworks are designed to retain the existing topography, protect natural features, and prevent erosion and slips. However, the measures to manage the risk from earthworks also require that such earthworks should not increase the vulnerability of people or their property to natural hazards such as erosion, landslip and flooding.

All earthworks in the Special Recreation, Passive Recreation, Hill Residential and Landscape Protection Residential Activity Areas and in Maire Street, Eastbourne, Lot 4 DP 14002, are restricted discretionary activities. Earthworks in all other activity areas are permitted provided the natural ground level is not altered by more than 1.2 m measured vertically and earthworks volume does not exceed 50 m^3 per site, and if these limits are exceeded, such earthworks also become restricted discretionary activities. These other activity areas may also contain areas of steep slopes and/or land instability, so there is a possibility that the current District Plan permits some earthworks at sites that are highly susceptible to slope failures. Restricted discretionary earthworks require consideration of areas prone to erosion, landslip and flooding, and should not increase the vulnerability of people or their property to such natural hazards and require resource consents.

Controls on vegetation clearance for each activity area are specified in Chapters 4 to 8. The extent and type of clearance permitted varies between different zones. For example, clearance is always permitted in Rural Residential Activity Areas, but consent is always required for clearance in General Recreation Activity Areas.

Subdivision activities are controlled by the rules in Chapter 11. Subdivision is generally a controlled activity in most zones, including the Hill Residential, Landscape Protection Residential, and Passive Recreation Activity Areas. This chapter outlines the standards that must be met during subdivision, including relevant codes relating to earthworks. From a natural hazards perspective, the objective is to ensure that land subject to natural hazards is subdivided in a manner that the adverse effects are avoided, remedied or mitigated, and to ensure that within each allotment there is a suitable building platform so that buildings and associated structures will not be adversely affected by slope instability, including the deposition of debris.

7.2 Options for planning controls

In order to manage the risk of slope failures to property and life in the Hutt City district, different controls on activities and development can be implemented in the District Plan. The slope failure susceptibility maps presented in this study can be used to inform these controls. The implementation of specific planning controls in the District Plan should be based on discussions between geotechnical engineers and planners, to ensure that controls are appropriate.

7.2.1 Controls for new subdivisions and buildings

Where possible, there should be a preference for avoiding the development of new subdivisions and new buildings in areas that of higher slope failure susceptibility. If development is to occur in these areas, then this should be for low-intensity development only. Areas of lower susceptibility should be used for high-intensity development.

Development in areas of lower slope failure susceptibility may be acceptable when developing new subdivisions and buildings, as engineered measures can be implemented to increase stability. Before considering such measures, there should be a thorough process of geotechnical investigation and design to assess the site-specific slope stability conditions.

7.2.2 Controlling for earthworks and vegetation clearance

In areas of higher slope failure susceptibility, limits on earthworks and vegetation clearance should be imposed to minimise alteration of existing slopes that can lead to exacerbated slope failure risks. These activities can further increase slope failure susceptibility. In lower susceptibility areas, earthworks and vegetation clearance will often have a lesser effect on slope stability, so these activities may be less restricted.

7.2.3 Geotechnical assessments of slope stability

Where land is considered susceptible to slope failures, the requirement for a geotechnical assessment by a suitably qualified and experienced geotechnical engineer can be implemented as a control by Council. Prospective developers should provide a report summarising such an assessment prior to applying for consent to develop in these areas. We recommend that the Council ensures that this assessment is done by an appropriately experienced Chartered Professional Engineer with geotechnical practice area or Professional Engineering Geologist registered with Engineering New Zealand.

A geotechnical assessment of slope stability should be completed following established guidelines, such as 'Practice Note Guidelines for Landslide Risk Mitigation 2007' (Australian Geomechanics Society, 2007). The report should demonstrate that the risk of proposed activities is not greater than a low risk to property and life, under these guidelines.

7.2.4 Areas of slope instability hazard

It would be prudent for the Council to ensure that development proposed in areas likely to be affected by slope instability are controlled through the district plan rules. The assessment and maps provided in this report classify the land in terms of their susceptibility of slope failure and can form the basis for such controls. In addition, it would be prudent to also manage the risk to properties not immediately on land prone to instability, but could be impacted by failures, either:

(a) Above slopes and subject to regression of slope failures back into less steeper areas
(b) Below slopes and are subject to hazards from deposition of failed materials and run out of debris from failure of slopes.

We would recommend that the district plan rules also consider potential landslide regression, deposition and runout hazards, including those originating from outside the property boundaries.

7.2.5 Provision of slope failure susceptibility information

In order to inform the public and prospective developers with relevant information on slope stability in the Hutt City district, the Council should provide information relating slope failure susceptibility and the existence of past landslides within the Land Information Memorandum (LIM) reports for individual properties.

7.3 Land Use Planning

It would be prudent for the Council to also use the slope hazard maps to inform land use planning, urban growth strategies and plan change proposals to ensure that areas zoned for future development do not create future landslide risks or additional costs to communities, and lead to resilience risks to roads and utilities serving these areas.

Such processes would benefit from advice from geotechnical engineers to ensure that:

a) Higher hazard areas are avoided in zoning for high intensity development and reserved for lower intensity land uses.

b) Lower hazard areas are chosen for high intensity development.

7.4 Other Uses of Hazard Maps

The slope failure hazard maps developed would also be useful for the Council's infrastructure departments in understanding the resilience of the services provided, planning and managing the development of new infrastructure, and for maintenance management and emergency response planning.

The Council's civil defence and emergency management groups will also benefit from these hazard maps.

8 Recommendations

We recommend:

1. Refinement of the maps of slope failure susceptibility presented in this study into a zoned overlay with specific rules and controls implemented in each zone.
2. Development of planning controls relating to slope failure susceptibility through discussions between geotechnical engineers and planners.
3. Consideration be given to assessing and mapping landslide runout and regression hazards in the Hutt City district.
4. Revisiting and updating the mapped slope failure susceptibility zones once newly acquired 2021 LiDAR data becomes available.
5. Capturing past landslides into the Hutt City Council database, so that these are widely known and can be used to update slope stability hazards, used to manage risk, and provided with LIM reports.

9 Limitations of the assessment

This study represents a district-wide appraisal of slope failure susceptibility to assist Hutt City Council in the implementation of land development planning controls.

This appraisal is based on regional-scale datasets along with elevation data and aerial imagery, and this should be appreciated in any use of the maps. Some site observations have been undertaken to validate mapping classification, but the maps should be used for district wide considerations.

The datasets used are appropriate for a regional study but not at the scale of individual properties. Assessments at individual property level have not been carried out, and no intrusive investigations have been completed to determine site-specific conditions. The actual slope failure susceptibility at a particular property may therefore differ from that shown in the maps from this study and would require more detailed site-specific investigation to confirm.

Given the district-wide nature of this study, the areas classed as Very Low or Low slope failure susceptibility cannot be taken to have no land instability. Property owners and developers should seek independent advice on land stability at their particular property, prior to development.

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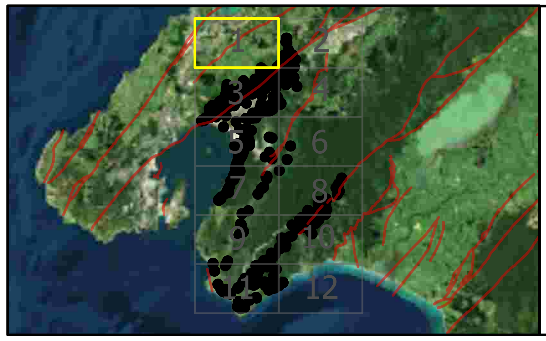
Appendix A
Slope failure susceptibility maps



Legend:

Slope Failure Susceptibility
- Very Low
- Low
- Moderate
- High
- Very High

- Hutt City district
- Building footprints
- Active faults
- Landslides

Prepared For: HUTT CITY TE AWA KAIRANGI

Prepared By: WSP

Title:
Slope Failure Susceptibility Assessment
Hutt City Council District Plan Review
Slope Failure Susceptibility Maps

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September 2021

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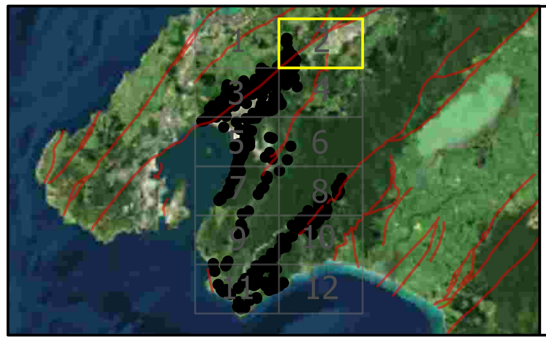
WSP Ref: 5-C4307.00



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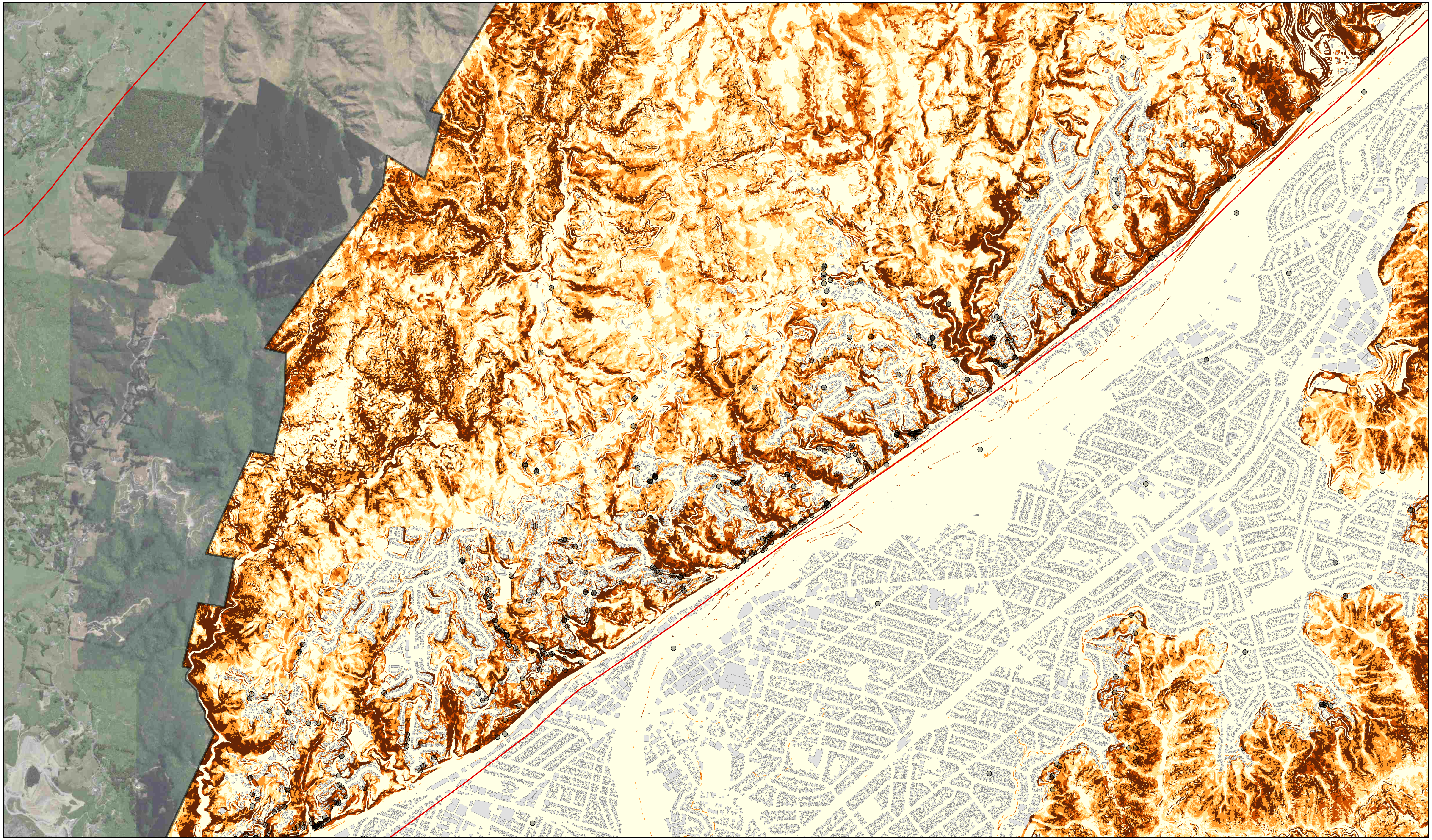

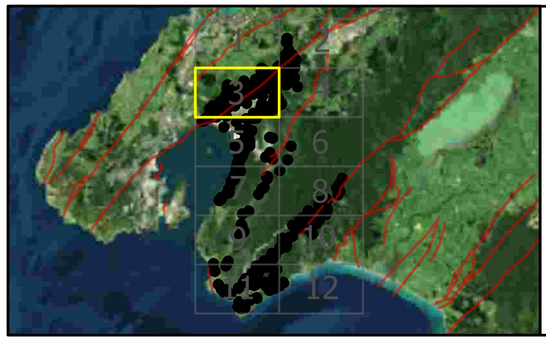

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- Low
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- Very High

- Hutt City district
- Building footprints
- Active faults
- Landslides

Prepared For: HUTT CITY TE AWA KAIRANGI

Prepared By: wsp

Title:
Slope Failure Susceptibility Assessment
Hutt City Council District Plan Review

Slope Failure Susceptibility Maps

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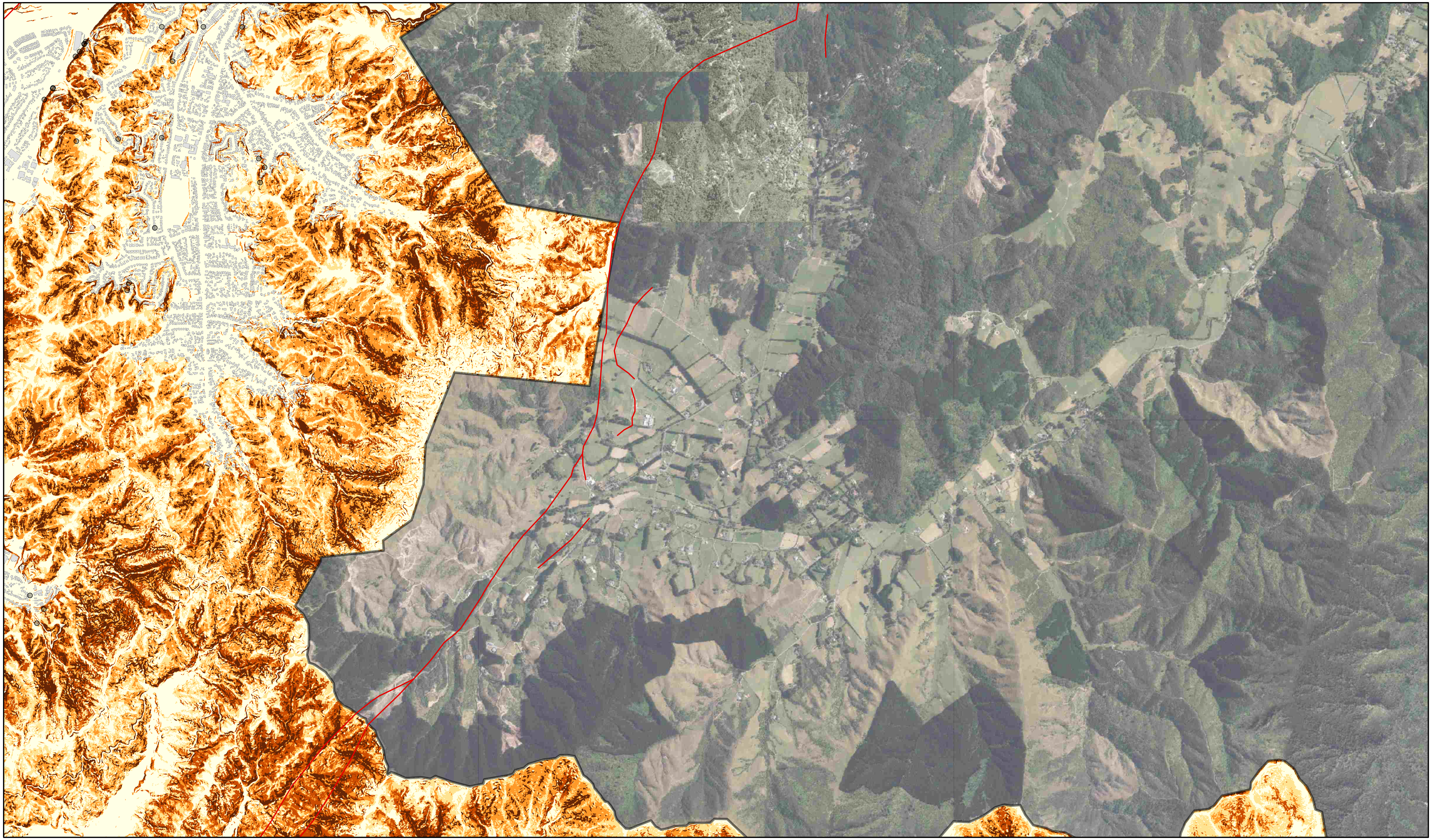
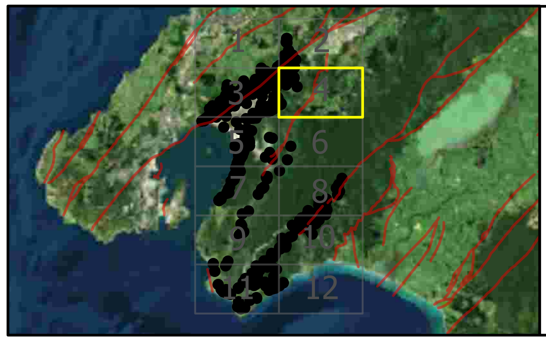
Date:
September 2021

Sheet:
3 of 12

WSP Ref: 5-C4307.00





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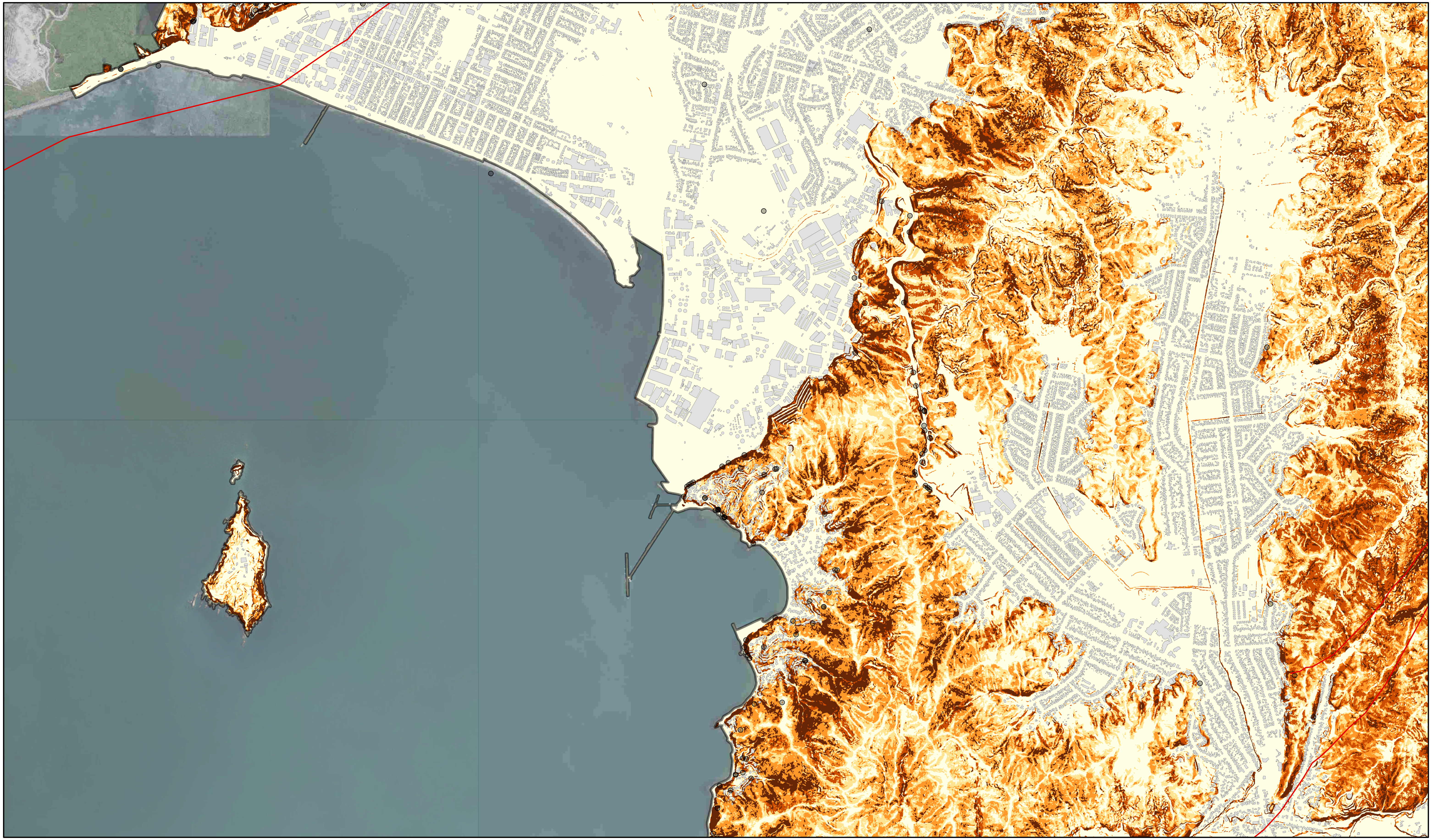
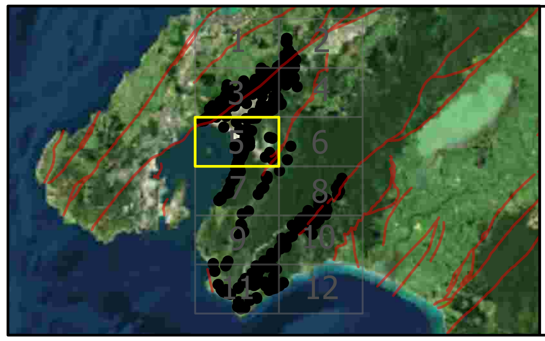
WSP Ref: 5-C4307.00





Legend:

Slope Failure Susceptibility

- Very Low
- Low
- Moderate
- High
- Very High

- Hutt City district
- Building footprints
- Active faults
- Landslides

Prepared For:

HUTT CITY TE AWA KAIRANGI

Prepared By:

wsp

Title:
Slope Failure Susceptibility Assessment
Hutt City Council District Plan Review

Slope Failure Susceptibility Maps

Date:
September 2021

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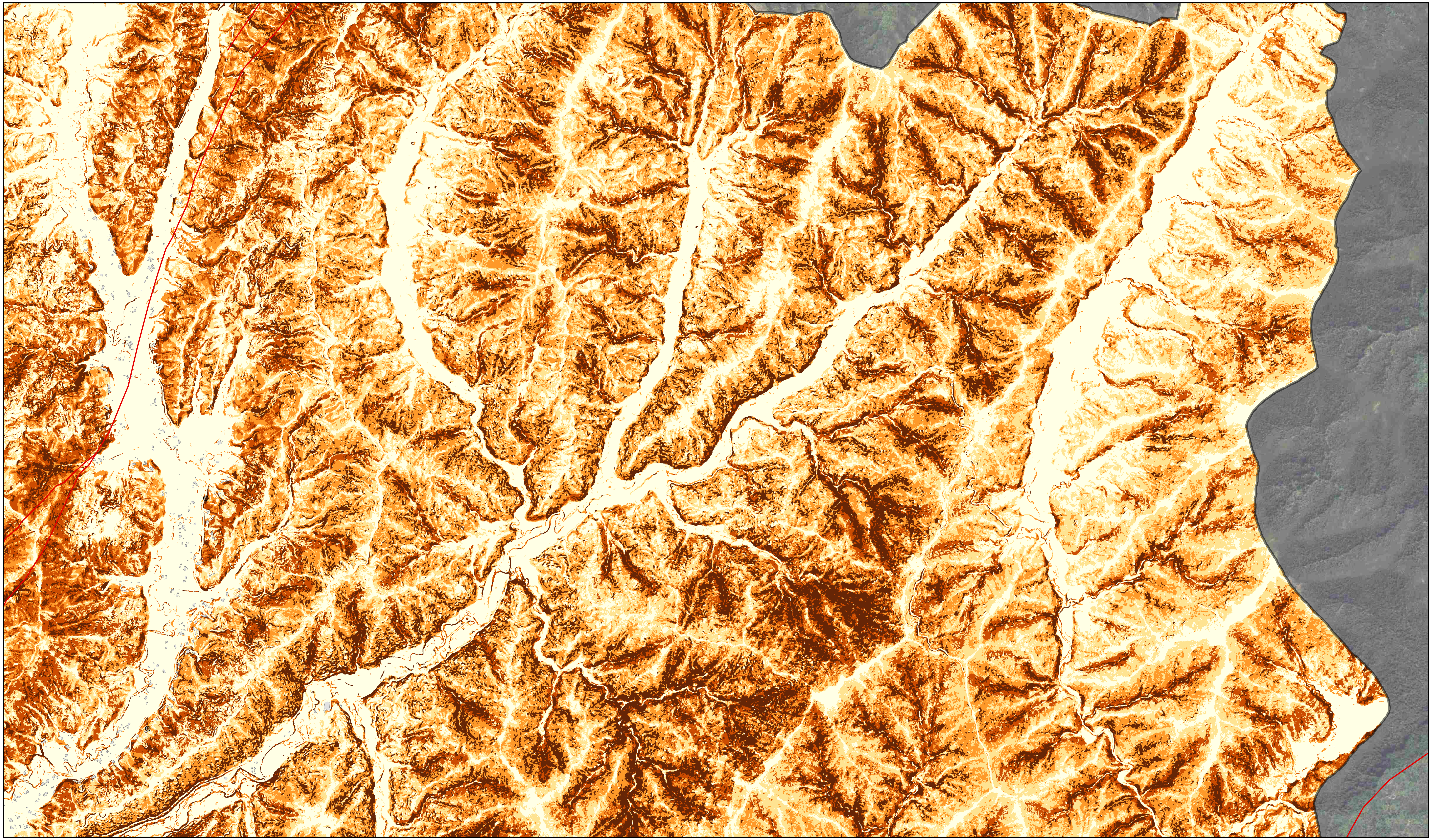

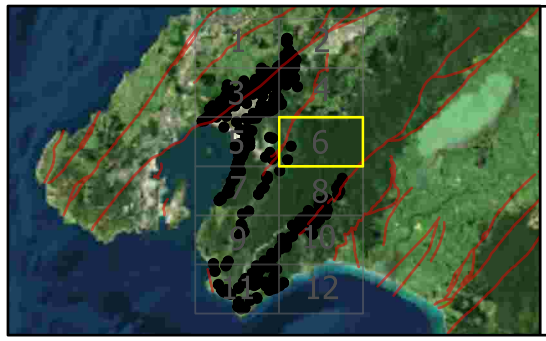

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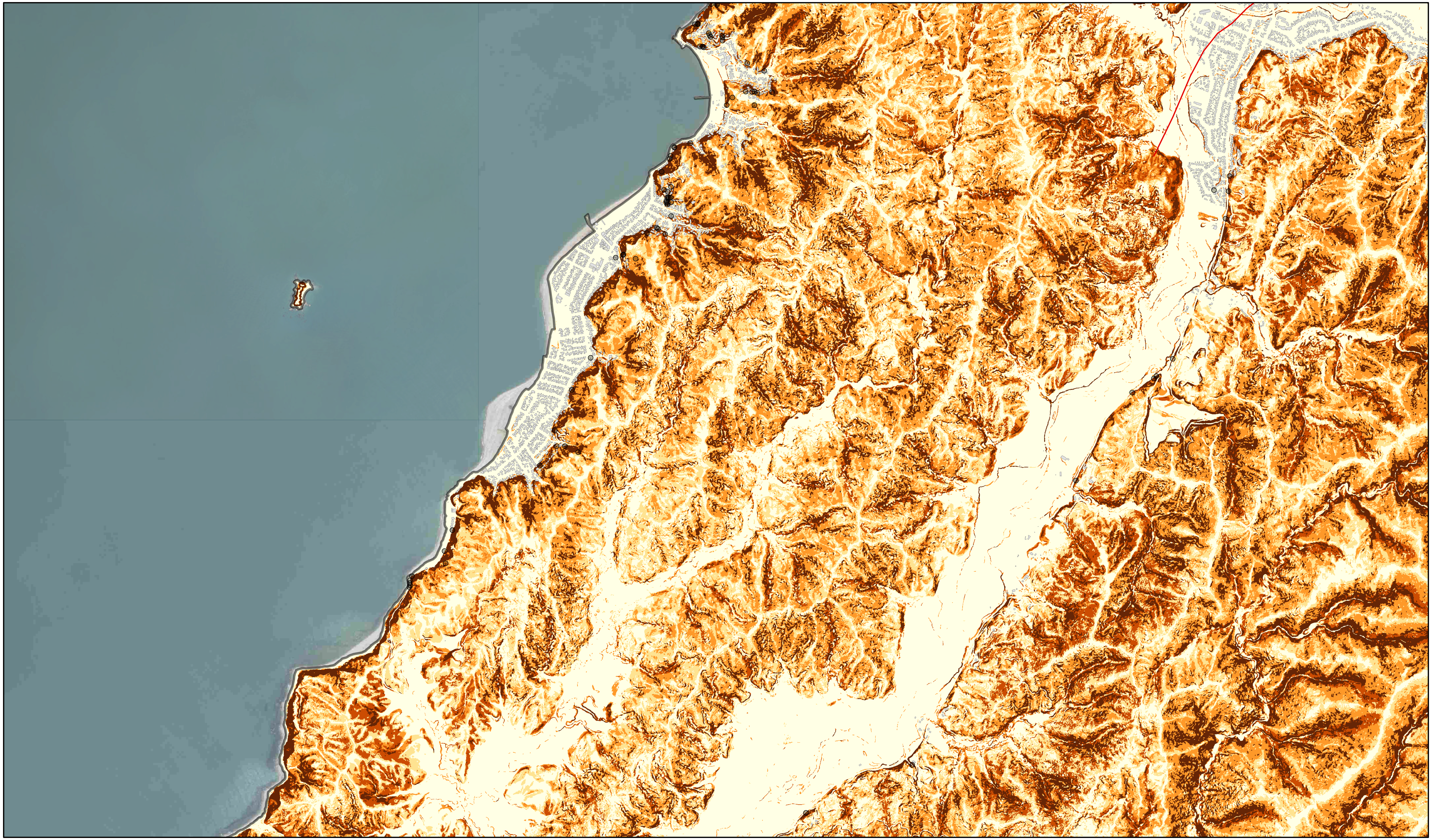

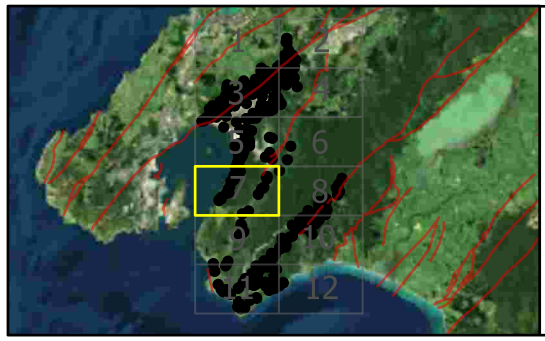

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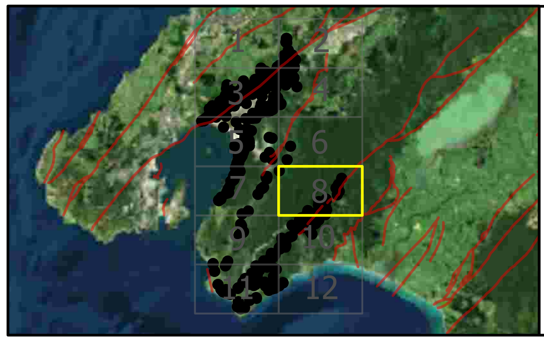

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Sheet: 8 of 12

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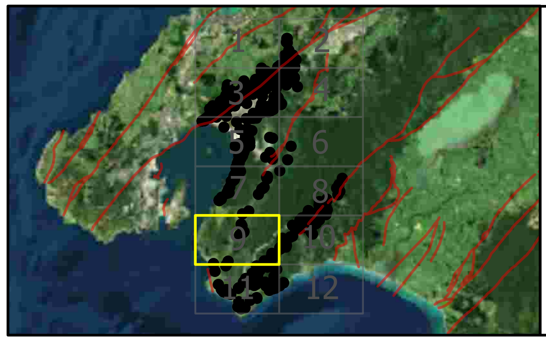

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Date: September 2021

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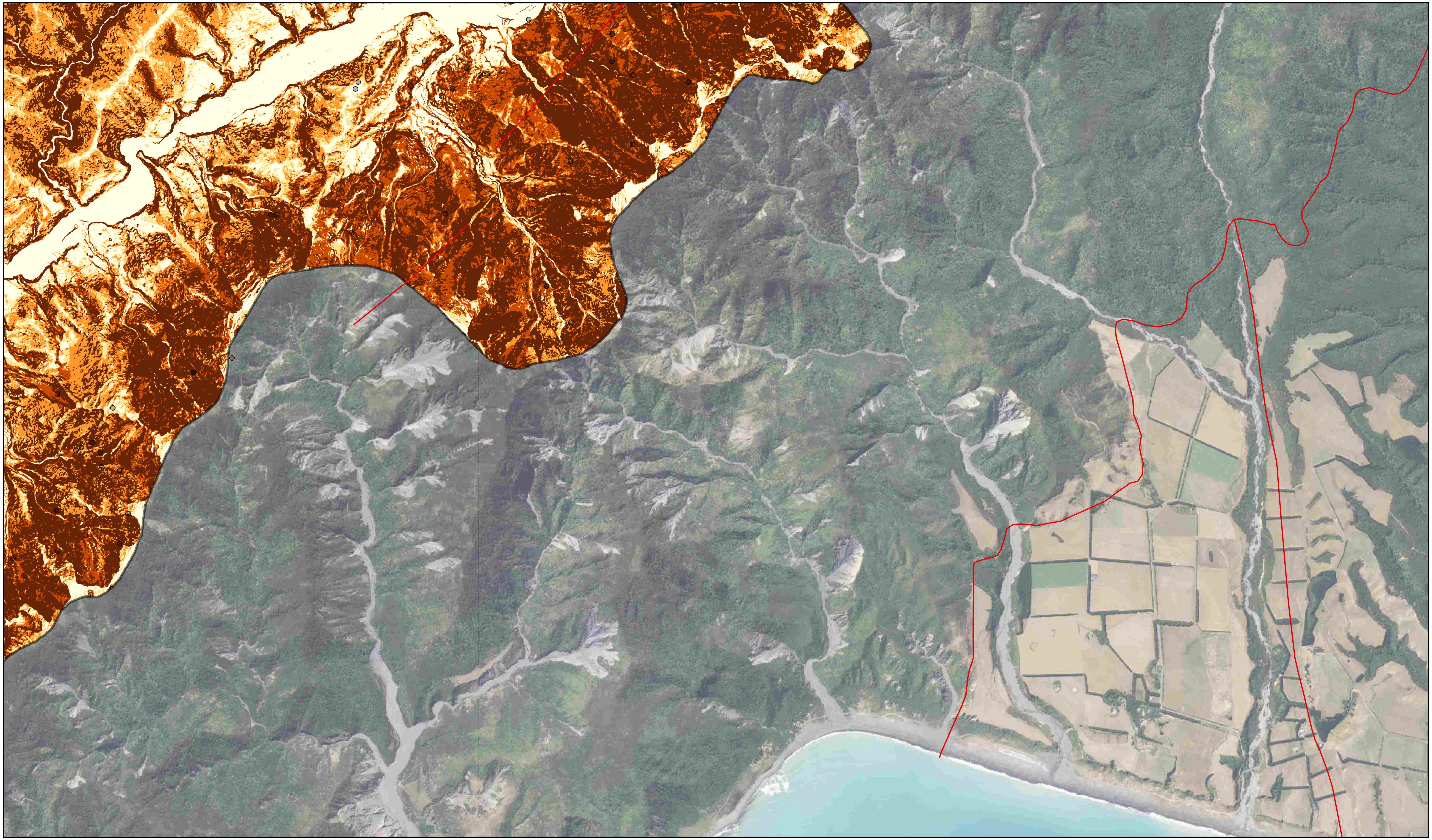

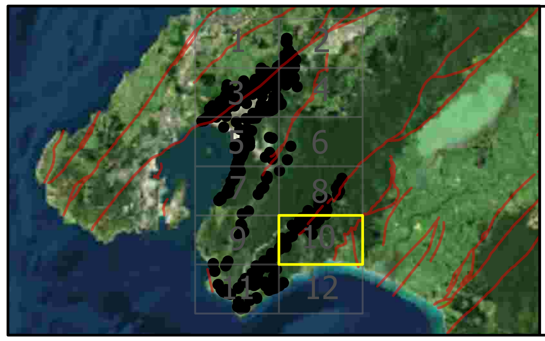

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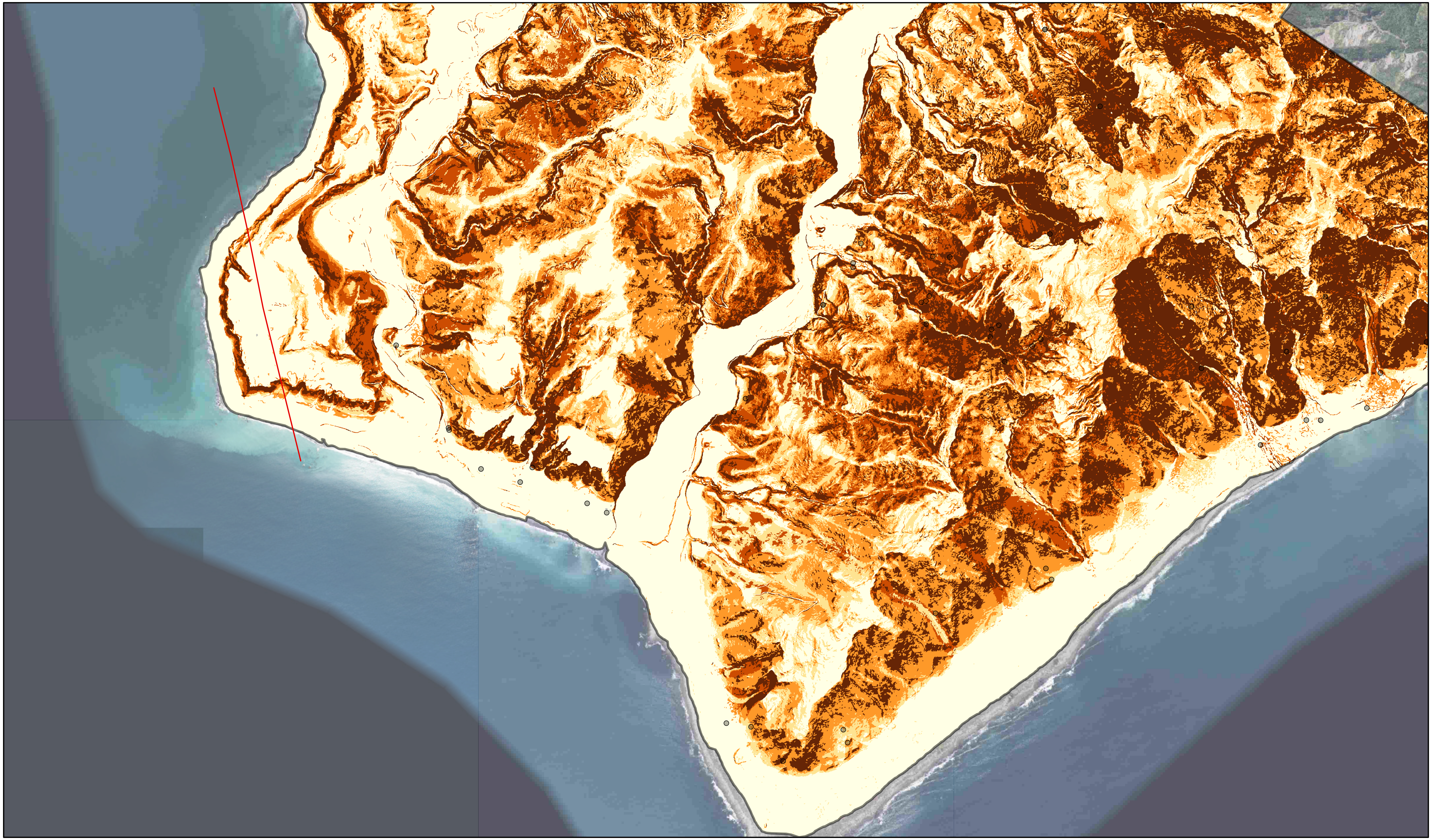

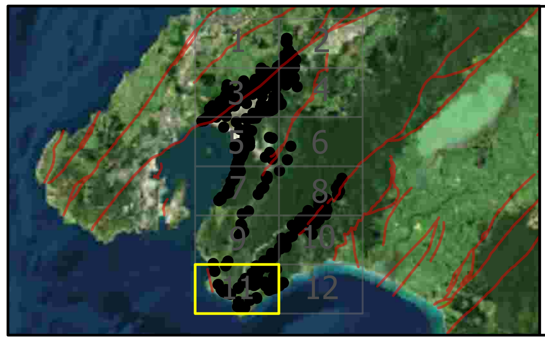

Legend:

Slope Failure Susceptibility

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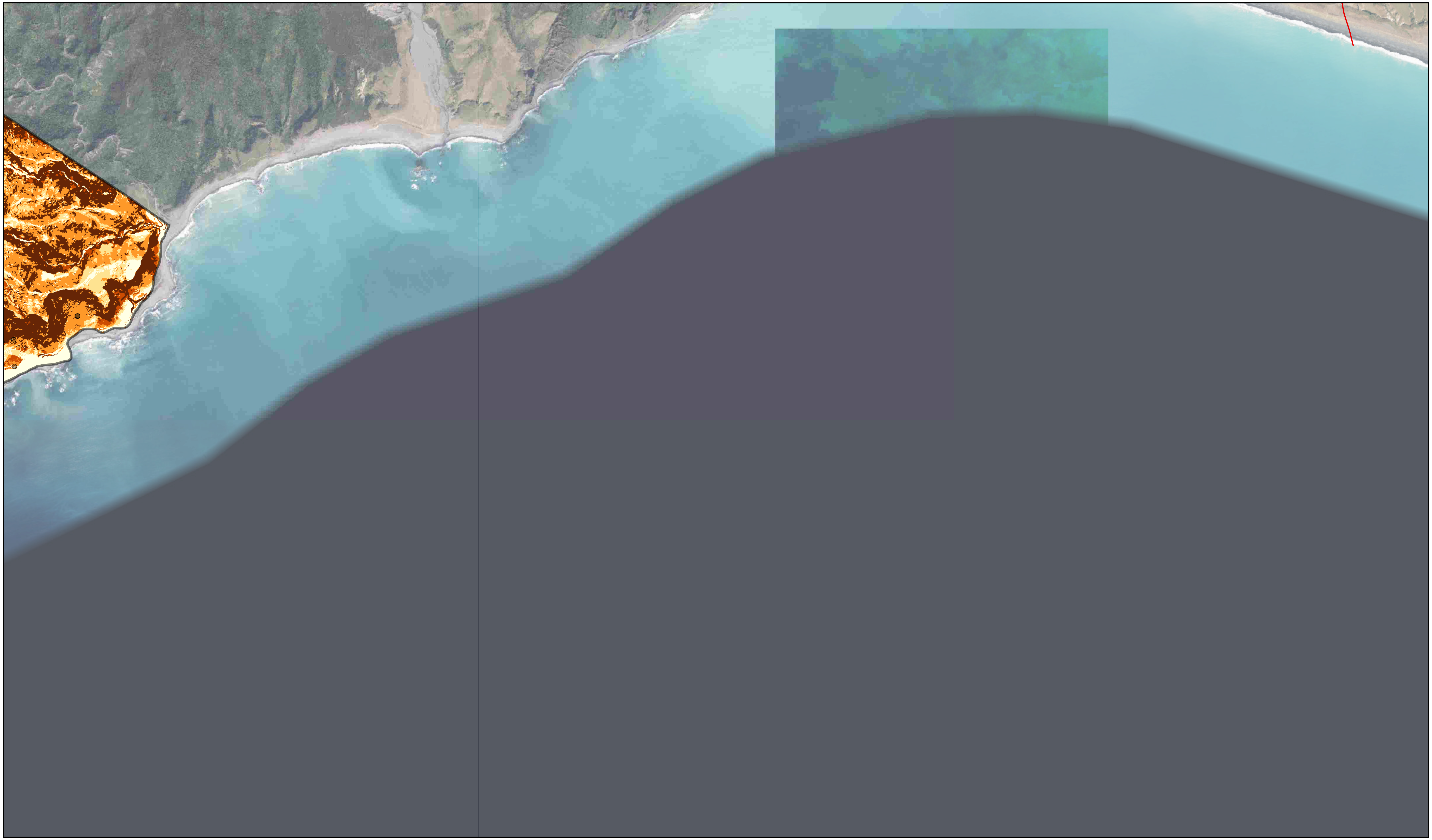

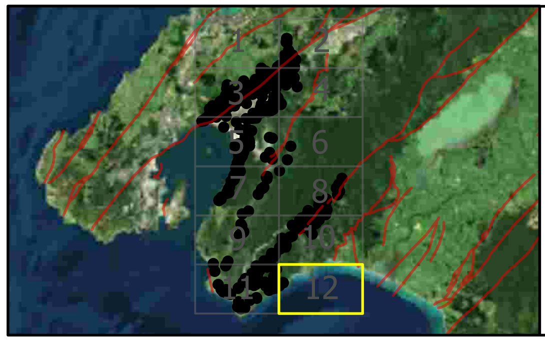

Legend:

Slope Failure Susceptibility	
Very Low	Hutt City district
Low	Building footprints
Moderate	Active faults
High	Landslides
Very High	

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Slope Failure Susceptibility Maps

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Date:
September 2021

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Appendix B
Significant storm events affecting the Hutt City district

Storm Event	Size (ARI and Daily Rainfall)	Impact
2 October 1941	99mm in 24 hours	Extensive flooding, widespread slips
14-15 February 1947	183mm in 24 hours	Severe erosion of the sea wall at Eastbourne, numerous slips on roads, widespread wind damage to property, railway washed out at Petone
27 June 1947	261mm in 24 hours at Wainuiomata	Parts of Lower Hutt flooded around Waiwhetu Stream and Petone, four main roads blocked by slips
22-23 May 1948	44mm in 24 hours at Tama St, Lower Hutt	Hutt River in high flood, 4m above normal at Lower Hutt Bridge, low-lying parts of Hutt Valley were inundated, Taita Gorge Road closed by storm damage
26-27 November 1952	99mm in 48 hours at Tama St, Lower Hutt	Widespread surface flooding in Naenae, Waiwhetu and other parts of Hutt Valley
23-24 May 1966	76mm in 24 hours	Flooding damage to roads, bridges and house in Lower Hutt, scour of a 1.8m hole halfway across a street in Stokes Valley
10 April 1968, ex-tropical Cyclone Giselle	105mm in 24 hours at Gracefield	High winds at Petone and Gracefield (181km/hr), power lost, roofs damaged, seas washed over road at Eastbourne, slips isolated Wainuiomata
20 December 1976	125mm in 24 hours at Wainuiomata, 153mm at Avalon, 264mm at Lower Hutt (1 in 50 year event up to 1 in 100+ year event)	Flooding, road and rail access between Wellington and Hutt Valley cut off, numerous slips, several houses demolished by flood water and mud, culverts under SH2 blocked forcing debris-laden water over the road, particularly at Korokoro Stream.
22 November 1977	82mm in 24 hours at Hutt Valley	Flash flooding, gale force winds, SH2 blocked by slips and flooding just north of Melling, railway flooded at Petone
21 May 1981	78mm in 24 hours at Central Hutt Valley, 116mm at Stokes Valley, 155mm at Wainuiomata	60 hours of non-stop rain causing slips on Wainuiomata Hill Road
10-12 December 1982	70mm in 24 hours at Stokes Valley	
11 April 1989	<20mm in 48 hours at Avalon and Taita	Some roads flooded, many closed due to slips, high winds brought down power lines in Petone
8-15 March 1990, ex-tropical Cyclone Hilda	72mm in 24 hours at Avalon (10/3/1990); 94mm in 24 hours at Taita (14/3/1990)	Flooding in Lower Hutt, with Stokes Valley the most severely affected (houses flooded)
8-11 April 1991	128mm in 3 days at Hutt Central, 145mm at Wainuiomata	

Storm Event	Size (ARI and Daily Rainfall)	Impact
16 October 1992	68mm in 48 hours at Maungaraki	Three houses in Stokes Valley evacuated due to a landslide, falling trees brought down powerlines
15 August 1994	84mm at Lower Hutt, 107mm at Wainuiomata	Flooding in Waiwhetu, Woburn, factories along Gracefield Road, SH2 blocked by small rockfall at Horokiwi, London Road and Normandale Road blocked by minor landslides, few slips on unmodified slopes in eastern hills.
4 October 1997	109mm in 24 hours at Lower Hutt, 88mm in 4 hours, 30mm in 1 hour	Extensive surface flooding, Hutt River reached 20 year peak, resulting in severe bank erosion, more than 60 homes flooded, Hutt motorway closed
26 June 1998	25mm in 24 hours, torrential rain in Wellington City (80mm in 1 hour 15 minutes in Karori)	
20 October 1998	72mm in 21 hours	House badly damaged by wind in Western Hills, Hutt River flooded, surface flooding
27-30 October 1998	66mm in 3 hours at Lower Hutt, 43mm in 24 hours at Wainuiomata	Widespread landsliding and flooding, some homes and schools evacuated. Western Hutt Road reduced to one lane due to slip.
2 October 2000	45mm in 24 hours at Maungaraki	Surface flooding reported on 30 streets in Hutt City, Hutt River rose rapidly
22 November 2001	104mm in 5 hours	A slip closed one lane on Hutt Road, surface flooding
10 January 2002	10mm in 24 hours recorded at Maungaraki	Localised, torrential rainfall caused flooding
17 June 2002	20mm in 24 hours at Maungaraki	Slips, flooding at least 1m deep near Melling Station, flooding to low lying areas near Hutt River
10 June 2003	123mm in 24 hours at Lower Hutt, 200mm at Wainuiomata	Several slips, widespread flooding, several streets in Woburn and Wainuiomata flooded
3-4 October 2003	78mm in 24 hours	Damage mostly confined to Kapiti Coast
20-21 January 2004	67mm in 48 hours at Maungaraki	Surface flooding on SH2, power cuts in Lower Hutt due to high winds, Eastbourne road flooded
15-16 February 2004	200mm in 24 hours at Eastbourne, 200mm at Lower Hutt (50 year ARI)	Road and railway services cut between Wellington and Lower Hutt, Eastbourne road also closed by a major slip, Wainuiomata cut off. Parts of Eastbourne evacuated due to slips, six homes in Stokes Valley hit by slips. Biggest flood damage in Hutt Valley for 25 years.

Storm Event	Size (ARI and Daily Rainfall)	Impact
18-19 August 2004	80mm in 24 hours at Lower Hutt, 96mm at Wainuiomata	Homes evacuated in Lower Hutt, Wainuiomata and Eastbourne due to slips and flooding, surface flooding, high winds downed trees, sea waves swept across railway at Petone
5-7 January 2005	80mm in 12 hours	Properties and roads flooded, Hutt River rose to 25 year levels causing stopbank erosion
30-31 March 2005	60mm-100mm in 24 hours	Wainuiomata River flooded, flooding farms, four landslides recorded
6 July 2006	142mm in 72 hours at Maungaraki	Debris flow damaged house at Eastbourne, houses evacuated. Slip at Horokiwi closed SH2 one lane each way
7 August 2006	34mm in 24 hours	Landslide in Kelson, which undermined a house. The house was demolished. Three surrounding houses also evacuated.
24 October 2006	200mm in 24 hours at Wainuiomata	Heavy seas washed onto roads and railway; high winds cancelled trains. Debris flows at Eastbourne damaged two properties.
8 October 2007	150mm in 6 hours, 33mm in 1 hour	Hutt River flooded, parts of Block Road closed, surface flooding (including up to 30cm deep water on SH2 between Upper Hutt and Petone)
1 March 2008	80mm in 24 hours	Slip on Marine Drive, York Bay, Eastbourne blocked both lanes
30 April – 1 May 2008	50mm in 12 hours	Flooding and landslides around the region
29 June 2008	99mm in 24 hours	Surface flooding, high winds
12 July 2008	26mm in 2 hours	Severe surface flooding on Western Hutt Road (SH2) at Normandale
19 July 2008	21mm in 24 hours, almost half of total falling in 1 hour	Flooding, high winds
29 July 2008	20mm in 72 hours at Maungaraki	Surface flooding, high winds brought down a tree onto railway north of Waterloo
6 August 2008	No rain on 6/8/2008 at Maungaraki, however 52mm in proceeding 72 hours	Landslide at Point Howard blocked road to Eastbourne, road closed overnight.
24-27 August 2008	19mm in 24 hours 25/8/08, 17mm in 24 hours 27/8/08 at Maungaraki	Marine Drive in Eastbourne flooded, house in Sunshine Bay evacuated after being badly damaged by a slip. Landslip onto SH2 at Petone overbridge, which closed the road for a few hours
20 February 2009, ex-tropical Cyclone Innis	83mm in 24 hours	Surface flooding
15 May 2009	10mm in 48 hours at Maungaraki	High winds damaged power lines, surface flooding

Storm Event	Size (ARI and Daily Rainfall)	Impact
31 August 2009	74mm in 24 hours at Maungaraki	
15-16 October 2009	54mm in 48 hours at Maungaraki	
June – October 2010		
14-15 May 2015	42mm in 1 hour at Avalon, 102mm in 24 hours at Lower Hutt	Flooding, Civil Defence emergency declared, 21 landslides recorded, mostly in Western Hutt hills, Korokoro Stream flooded, disrupting SH2 traffic.
16 November 2016	65mm in 24 hours	Flooding
3-5 September 2018	75mm in 24 hours	
7-8 December 2019	68mm in 24 hours	Flooding, particularly in Stokes Valley and Haywards Hill

Appendix C
Typical slope failure mechanisms in the Hutt City district

Failure Type	Slope Details	Slope Modifications contributing to failure / failure triggers	Consequences	Example	Example Photo
Rock falls	Typically occurs from closely jointed, steep greywacke slopes, either unvegetated or with low vegetation.	Cut slopes, cut too steeply, with adversely oriented defects. Rock falls often occurs during and following heavy rainfall events.	Usually small volume (<20 m^3) rockfalls and overslips, which fall close to the source. Larger boulders can roll or bounce further downslope if the slope below the source allows (up to several hundred metres)	SH2, Petone, 29 June 2020: Rock fall from a 13 m high, 70° to 80° cut slope onto SH2. Failure surface was a steep, planar joint set dipping subparallel to the cut slope.	
Rock slides / wedge failure	Development of planar or wedge-shaped failures along adversely oriented defects within the greywacke bedrock. Defects are typically persistent joints or crushed/sheared zones which are often bedding parallel.	Can occur in rock cut slopes, which may be oversteepened. Often triggered by heavy rainfall events.	Rock slides result in debris onto roads and property, and can undermine properties at the headscarp of the failure. Typical failure volumes are <10 m^3 up to 500 m^3 or greater	SH58, Haywards, 11 December 2020: Shattered bedrock in the upper section of a 65° rock cut slope failed along sheared zones or bedding visible in headscarp. Debris from the slide filled the road shoulder.	
Soil failure	Surficial failures of topsoil, loess, alluvium, colluvium or fill, typically as a result of heavy or intense rainfall. Failures often develop as retrogressive failures in catchments of small drainage channels, or soil failures following vegetation loss on steep slopes.	Poor drainage conditions within the slope, removal of vegetation or excavation of the toe can increase the likelihood of failure. Often triggered by heavy rainfall events. Can also occur as a result of earthquakes, with failure along the soil/rock interface.	Soil failures result in debris onto roads and property and can undermine properties at the headscarp of the failure. Typical failure volumes are <10 m^3 up to 200 m^3 or greater	Residential failure in Naenae, 27 September 2020: Failure of residual soil (silty clay with gravels) from a 2 m to 3 m high, ~70° cut slope behind a dwelling, causing inundation behind the house, damage to services and a loss of 1 m^2 of land at the headscarp.	

Failure Type	Slope Details	Slope Modifications contributing to failure / failure triggers	Consequences	Example	Example Photo
Debris flow	Loose, dry or saturated debris mobilised downslope, typically down a pre-existing channel. Slope angles typically 20° to 40°.	Debris flows have occurred in areas where there has been vegetation removal upslope of developed areas. They are triggered by earthquake shaking, or later by heavy rainfall following an earthquake, or by heavy rainfall events mobilising poorly vegetated soils.	A debris flow forms a fan when the channelised flow meets a plain or gentler slope (< ~4°). The fan can inundate houses, roads and other infrastructure at the bottom of the channel. Debris volumes were analysed by Massey et al. (2019) and found to be between 15 m^3 and 11,000 m^3, but smaller volumes (<100 m^3) are more prevalent.	Sunshine Bay, Eastbourne, 24 October 2006: Two large debris flows, initiated as shallow soil slides in an area of recent pine felling, were triggered by intense rainfall. Two houses were damaged and eventually abandoned. Photo from Hancox et al. (2006).	
Fill embankment failure	Gullies are often filled with granular material to provide a larger platform for residential development, roads and other infrastructure.	Failure of fill slopes is often triggered by heavy or prolonged rainfall events, particularly when fill slopes are steep or poorly compacted during construction and have high natural groundwater levels. Uncontrolled stormwater discharge or removal of vegetation cover may also trigger failure.	Inundation of property or infrastructure at the toe of the failure, with loss of land and possible damage to buildings at the headscarp. Damage to services buried within the fill embankment. Typical failure volumes are 100 m^3 to 10,000 m^3.	Residential failure in Kelson, 8 December 2019: Failure of fill slope following a prolonged heavy rainfall event, causing inundation of land below failure and loss of approx. 30 m^2 of property at the headscarp.	

References
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Massey CI, Thomas KL, King AB, Singeisen C, Horspool NA, Taig T. 2019. SLIDE (Wellington): vulnerability of dwellings to landslides (Project No. 16/SP740). Lower Hutt (NZ): GNS Science. 76 p. (GNS Science report; 2018/27)

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