Hutt City Council

SLOPE FAILURE RUNOUT ASSESSMENT

HUTT CITY DISTRICT PLAN REVIEW

28 JANUARY 2025

CONFIDENTIAL

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HUTT CITY COUNCIL DISTRICT PLAN REVIEW

Hutt City Council

Report No. GER 2024 - 58

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REV	DATE	DETAILS
0	28 May 2024	Draft for Issue
0.1	7 June 2024	Updated Draft for Issue Appendix A and B Maps
FINAL	21 January 2025	Final for Issue

	NAME	DATE	SIGNATURE
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DISCLAIMERS AND LIMITATIONS

This report ('Report') has been prepared by WSP New Zealand Limited ('WSP') exclusively for Hutt City Council ('Client') in relation to the assessment of slope runout in the Hutt City District ('Purpose') and in accordance with the Offer of Service dated 13 February 2024 and the Short Form Agreement with the Client dated 23 February 2024 ('Agreement'). The findings in this Report are based on and are subject to the assumptions specified in the Report and our Offer of Service dated 13 February 2024. WSP accepts no liability whatsoever for any use or reliance on this Report, in whole or in part, for any purpose other than the Purpose or for any use or reliance on this Report by any third party.

In preparing the Report, WSP has relied upon topographical data, geological maps, asset data, landslide inventory and other information ('Client Data') provided by or on behalf of the Client. Except as otherwise stated in the Report, WSP has not verified the accuracy or completeness of the Client Data. Conclusions and recommendations in this Report are based on the Client Data, and those conclusions are contingent upon the accuracy and completeness of the Client Data. WSP will not be liable in relation to incorrect conclusions or findings in the Report should any Client Data be incorrect or have been concealed, withheld, misrepresented or otherwise not fully disclosed to WSP.

This study represents a district-scale assessment of the potential for landslide hazards to occur across the Hutt City area. This assessment has been completed through a review of desktop information, mapping and photography. It is not intended to precisely describe landslide risk at an individual property level. Actual risk for an individual property should be determined through appropriate site specific investigations, analyses and reporting completed by a competent Geo-Professional.

EXECUTIVE SUMMARY

Overview and background

Hutt City Council is undertaking a comprehensive review and update of the District Plan, with a particular focus on the Natural Hazards chapter. Recognising the need for improved understanding of landslide risks, the Council commissioned a slope runout assessment to identify areas vulnerable to landslide debris impacts and develop appropriate landslide susceptibility zone overlays for the District Plan.

As a first step WSP carried out a technical assessment of slope failure susceptibility for the Council (WSP, 2021). This first step assessment identified areas prone to slope failures but did not address the potential runout zones, which are crucial for understanding the full extent of landslide hazards.

Current Assessment and methodology

As a follow step, the Council engaged WSP to:

1. Carry out a slope runout assessment.
2. Identify areas at risk of inundation from upslope instability.
3. Develop landslide susceptibility overlays for integration into the District Plan.

The assessment methodology involved a desk study and GIS-based mapping of slope runout zones. An empirical method was chosen to determine slope runout due to the impracticality of using runout modelling methods for this district-wide study.

A Fahrböschung angle of 35˚ was used to estimate potential runout distances, deemed representative for district-wide assessment despite variations in slope heights, substrates, and trigger mechanisms. The assessment included various types of landslides, excluding debris flows, which typically have longer runout distances and shallower angles.

The focus was on residential activity areas specified in the district plan, excluding rural residential and rural zones.

Key Findings and Technical Details

- Identified and mapped areas susceptible to landslide debris impacts at a scale of 1:5,000. These zones were combined with slope failure susceptibility data to create a landslide susceptibility overlay.
- Detailed maps of the individual runout and failure zones ,and combined landslide failure and runout zones are included in Appendix A and B at a scale of 1:15,000.

Recommendations

- Implement District Plan measures to manage development in the identified hazard zones.
- Regularly update the landslide susceptibility overlay with new data and field observations to maintain accuracy and relevance.

This assessment provides Council with tools to enhance planning and hazard management, ensuring the safety and resilience of residential communities against landslide risks. The findings provide insights for managing slope stability issues through informed land use planning, subdivision, and development controls.

1 INTRODUCTION

Hutt City Council (the 'Council') is currently undertaking a full review and update of the District Plan, including the Natural Hazards chapter of the Plan. As part of the review and update, it was recognised that Council requires a better understanding of the hazard, and location of areas, that are at risk of landslides to further inform the management of land use, subdivision and development.

WSP previously delivered a first stage technical assessment of slope failure susceptibility across the district for Council (WSP, 2021). The assessment showed areas where slope failure could occur, but not areas that would be inundated (i.e. runout) from an upslope instability, which is an important aspect to capture.

The Council has commissioned WSP to carry out as the second stage, an assessment of slope runout to identify areas, including their extent, that are potentially subject to inundation by upslope instability, and develop overlays for the District Plan. This assessment will be used to inform Council on areas that may warrant controls in the District Plan to manage landslide hazards in relation to land use planning and development.

This report details our methodology, which includes a desk study and slope runout assessment and mapping. It provides an appraisal of stability issues in the Hutt City district, and recommendations for measures to manage the effects of land instability hazards.

This report should be read in conjunction with WSP's Slope Failure Susceptibility Study (WSP, 2021)

1.1 PREVIOUS REPORTING

In 2021 WSP undertook a technical assessment of slope failure susceptibility across the district for Council (WSP, 2021). The objective was to enhance understanding of slope failure susceptibility in the Hutt City district, to inform Council decisions on controls on development, to ensure that development activities do not exacerbate or are not impacted by these hazards.

As part of that study the geology, geomorphology and characteristic mechanisms of landsliding across the district were determined, based on the results of a literature review of available information. The factors that influence slope stability were identified and included a correlation to an inventory of previous landslides collated from Council and WSP records.

The assessment of the slope failure susceptibility was undertaken based on the weighting of the influencing factors and combining these in a Geographic Information System (GIS) platform using available geospatial datasets. Five categories of slope failure susceptibility were described, from Very Low to Very High (Figure 1). Characteristic slope morphologies within each slope failure susceptibility class were mapped across the district in GIS showing the spatial distribution and extent of the different categories.

The report also provided suggestions for giving effect to the study in the District Plan, and included 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 slopes.

Information gathered for the landslide susceptibility study and the results of that study were used in this slope runout assessment, and we refer the reader to the WSP (2021) report for more detailed information on landslide mechanisms and susceptibility within the Hutt City district.

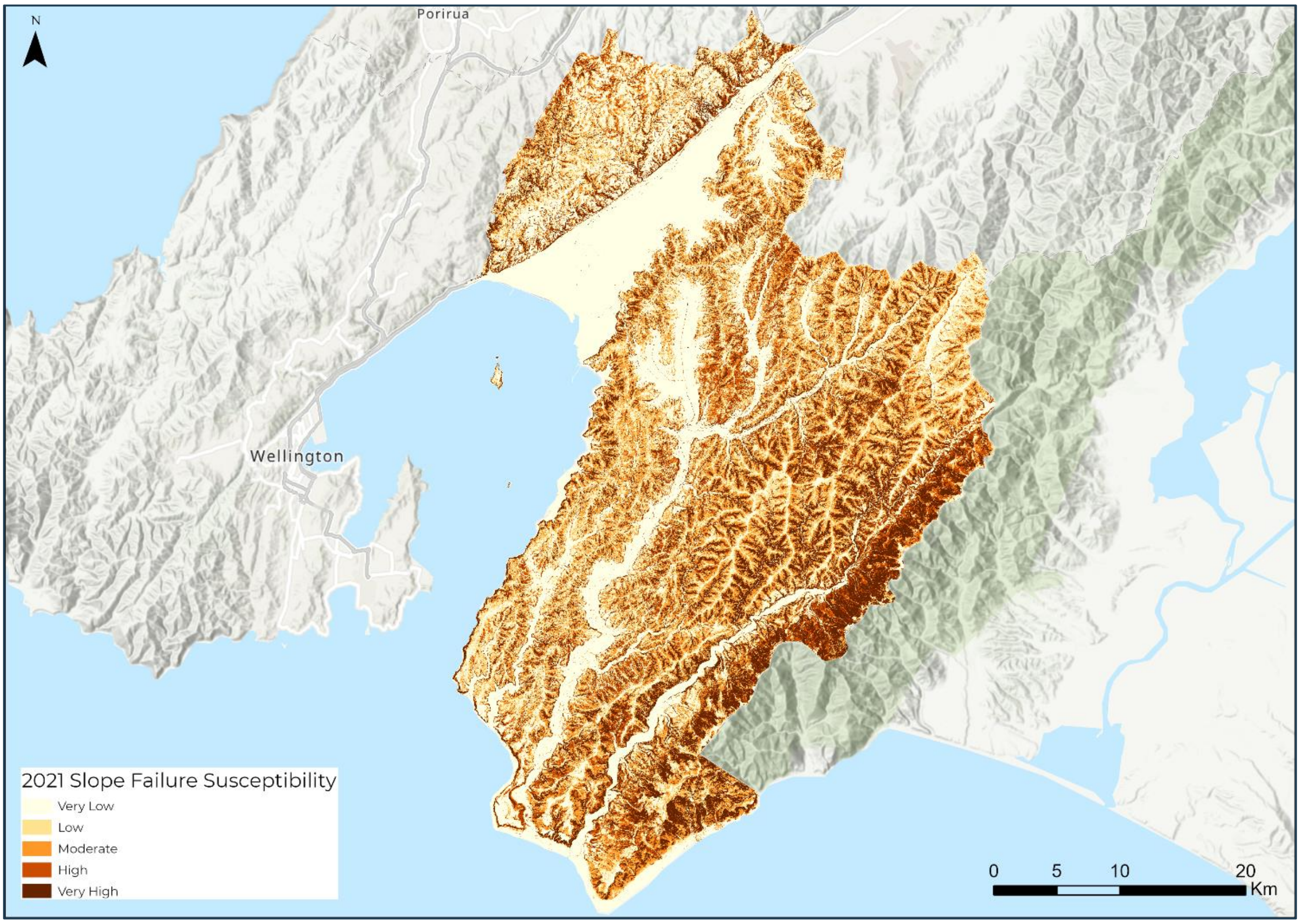
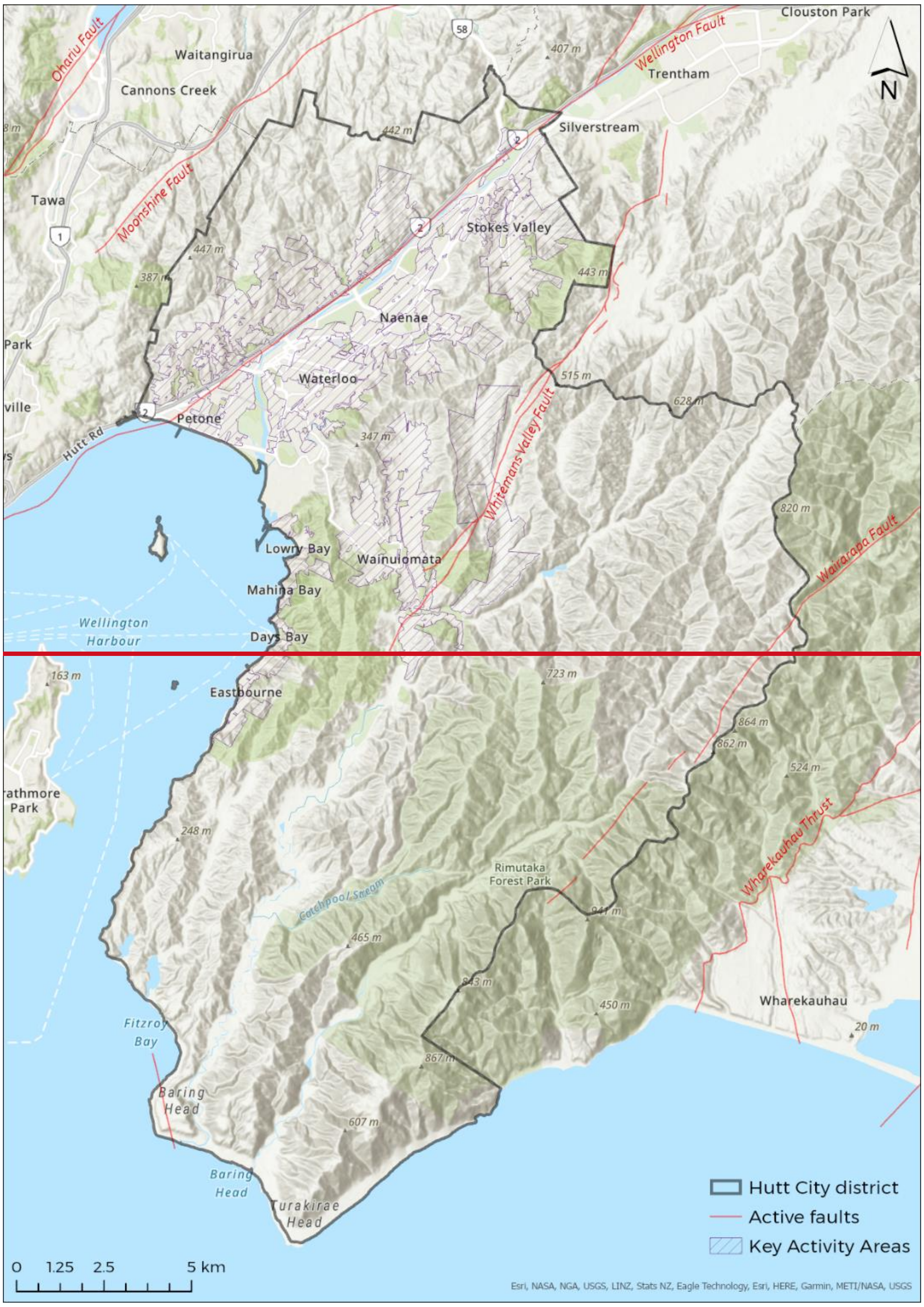


Figure 1: 2021 Slope Failure Susceptibility study results within the Hutt City District

2 STUDY AREA DESCRIPTION

2.1 LOCATION

Hutt City district is located in the southern part of the North Island and includes the city of Lower Hutt. The district borders Porirua to the northwest and north, Upper Hutt to the northeast, South Wairarapa District to the east, and Wellington to the southwest and west (Figure 2) and covers an area of approximately 375 km^2.


Hutt City district
Active faults
Key Activity Areas
0 1.25 2.5 5 km
Esri, NASA, NGA, USGS, LINZ, Stats NZ, Eagle Technology, Esri, HERE, Garmin, METI/NASA, USGS

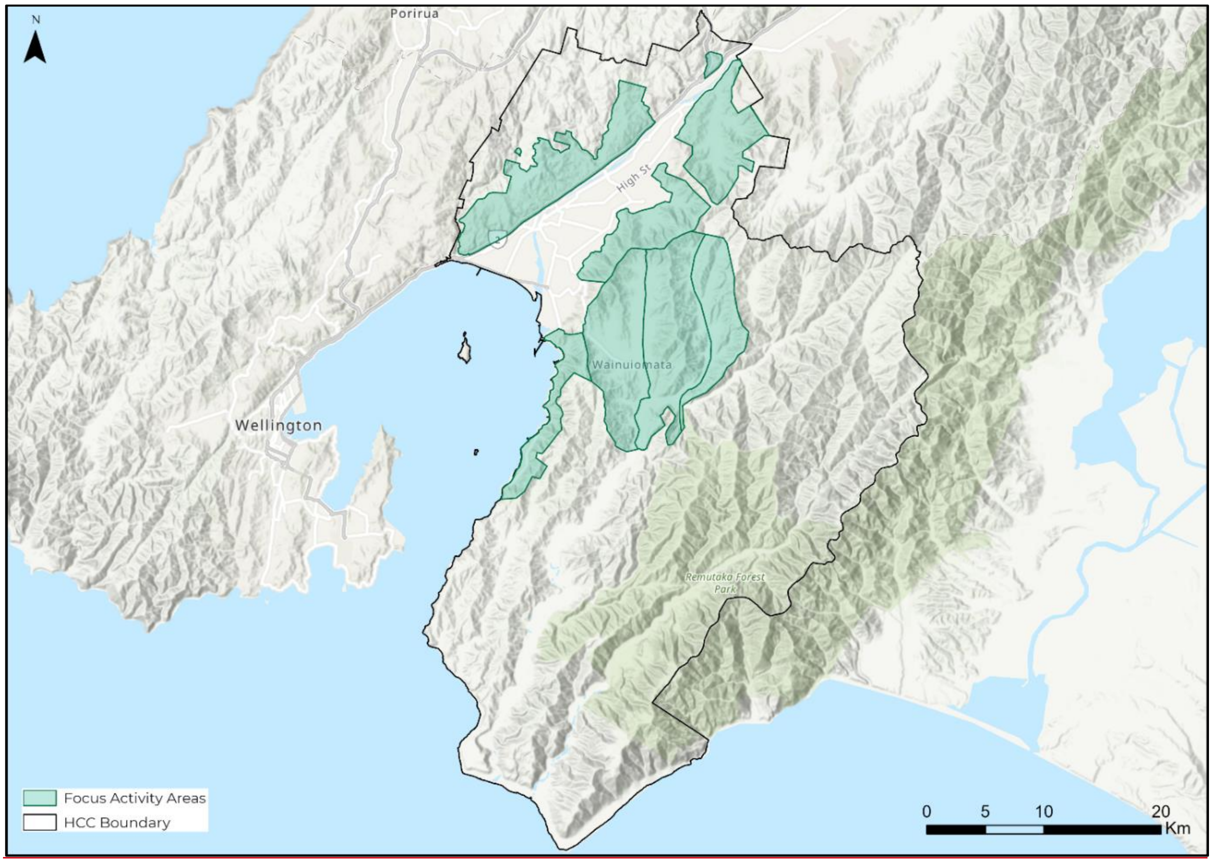


Figure 2: Hutt City District boundary with focus activity areas of study.

2.2 GEOMORPHOLOGY

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

Valleys within the Hutt City district are divided and bound by areas of hill terrain. 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 up to 450 m above sea level on either side of Hutt Valley. Several suburbs are located in the hills and slopes have been modified for residential development with cuts, fills and retaining walls.

Ridge-top areas in the Western Hutt Hills are generally flat or gently rolling, in contrast with the surrounding steep hillslopes and sharp ridges 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 Remutaka Ranges, on the eastern side of the district, rise to up to 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 typically comprises regenerating native forest and scrub, with smaller patches of mature native and exotic vegetation.

The main valley is Hutt Valley, which extends northeast to southwest from the northern extent of the district at Taitā Gorge to the harbourfront at Petone. Other prominent valleys include Stokes Valley and Wainuiomata Valley.

Coastal geomorphology is varied in the Hutt City district. Steep bedrock cliffs, sometimes more than 200 m high, are present at locations particularly on the south coast. Gently sloping beach and dune environments are in Petone and Eastern Bays harbourfront areas, as well as to the south of Pencarrow Head and the Wainuiomata coast.

2.3 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 & Johnston, 1996; Begg & Johnston, 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 its long and complex history of tectonic deformation. The hill terrain in the Hutt City district is underlain by greywacke materials that are generally closely fractured and variably weathered.

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 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.

2.4 SEISMICITY

The Hutt City district is an area of significant seismicity. The New Zealand Active Faults Database (https://data.gns.cri.nz/af/, 1:250,000 scale) shows four active faults within the Hutt City district, and 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 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 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 region, elsewhere in New Zealand, or from the Hikurangi subduction zone.

3 DESK STUDY

3.1 LANDSLIDES IN HUTT CITY DISTRICT

The WSP (2021) report includes an account of historic landslide records, which served as the foundation for developing a landslide inventory. This inventory has been updated to include 58 additional landslides reported by the Council, which occurred between 2021 and March 2024 (Figure 3). These newly added records primarily document landslides occurring in road corridors and around residential properties, identified by specific street addresses, and previously known residential landslides catalogued by WSP.

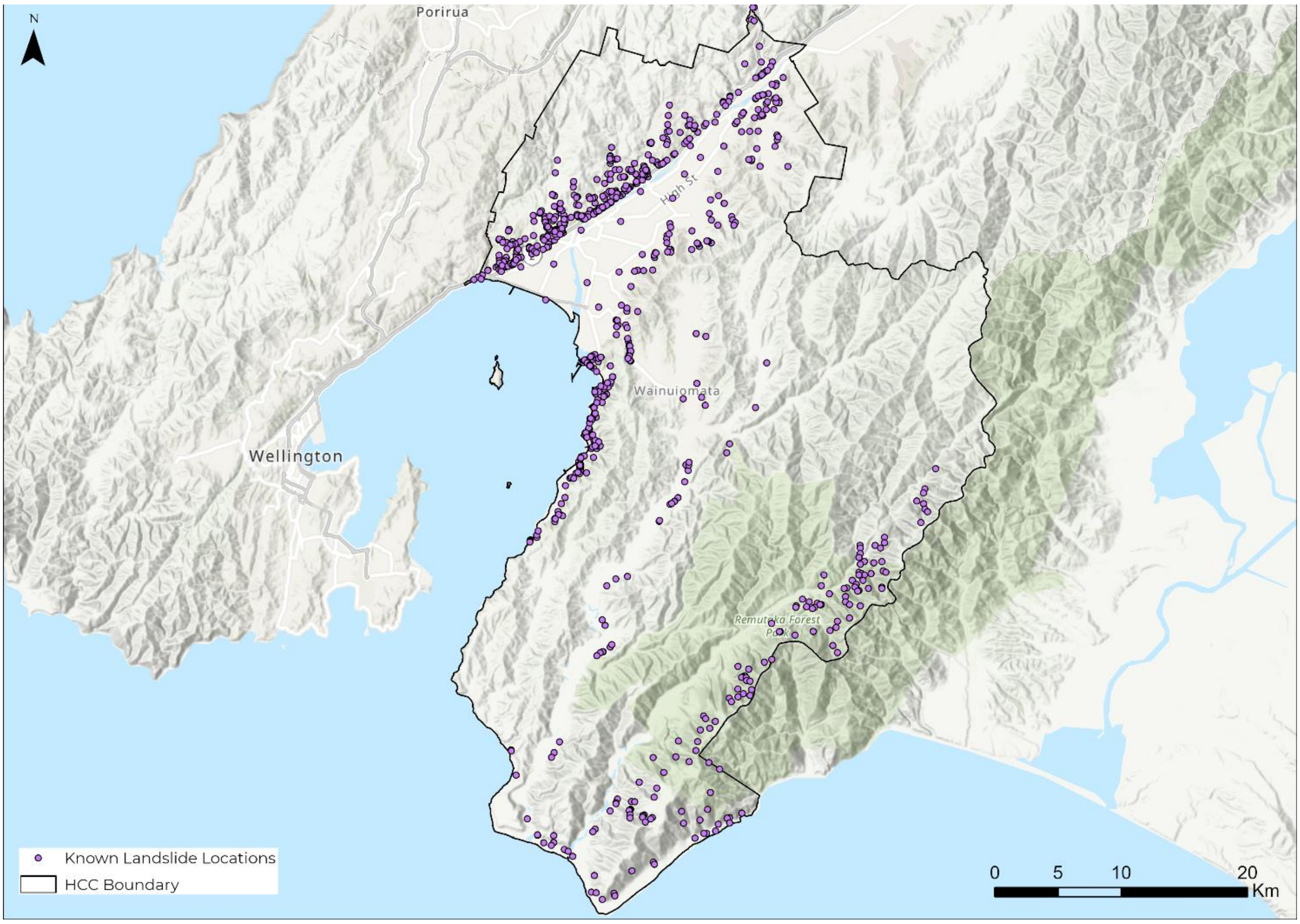


Figure 3: Updated landslide inventory for the Hutt City District

For residential landslides, where possible, the runout was mapped as part of this study based on inhouse WSP information gathered for external clients. The runout volumes of these residential landslides varied significantly, ranging from 1 to 82.5 m^3. Similarly, the runout lengths varied from 0.5 to 28 m.

The locational accuracy and extent of data available for each landslide in the inventory is variable, for example many of the landslides in the inventory reflect just the property address rather than the actual landslide position, and lack specific information about the volume and extent of the landslide.

3.1.1 TYPICAL FAILURE MECHANISMS AND RESULTING RUNOUT

The typical mechanisms contributing to slope failure within Hutt City district were summarised by WSP (2021) and include rock falls, rock slides, soil slides and debris flows. Slumping has also occurred in areas of fill typically associated with residential and transportation development. A summary of the characteristic failure types and associated runout is presented in Appendix C.

Rock falls and rock slides commonly occur from steep greywacke slopes, particularly where these are modified (steepened) by cutting for roads or residential developments. 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. Failure is often triggered by heavy rainfall events, and can also be triggered by earthquakes.

Rock fall events are typically small volume (<20 m^3) rockfalls and overslips, which fall close to source. Larger boulders can roll or bounce further downslope (up to several hundred metres) if the slope below the source allows.

The characteristic rock slides typically observed within the district have failure volumes[1] from 10 m^3 up to c. 500 m^3, and result in runout of debris onto roads and private property.

Shallow soil slides are common in the surficial regolith materials overlying greywacke bedrock, particularly if a slope is bare or lightly vegetated. Poor drainage conditions within the slope, removal of vegetation or excavation at the toe can increase the likelihood of failure. Failure is typically because of heavy or intense rainfall, however these can also occur as a result of earthquakes, with failure often occurring along the soil/rock interface. The volumes of failures typically observed in the district are greater than 10 m^3, and result in debris inundation of roads and private property.

These shallow failures can transition 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 significantly longer than translational failures (slides and slumps), particularly if they become channelised. Where the channelised flow meets a plain or gentler slope the debris flow can spread laterally to inundate houses, roads, and other infrastructure. The volumes of debris flows triggered in the Kaikōura area after the 2016 earthquake were analysed by Massey et al. (2019) and observed to be between 15 m^3 and 11,000 m^3, with smaller volumes (<100 m^3) being prevalent.

Failure can also occur of fill embankments, often triggered by heavy or prolonged rainfall events, particularly when fill slopes are steep or poorly compacted. Uncontrolled stormwater discharge or removal of vegetation also increases the susceptibility of these slopes to failure. Typical failures can result in inundation of property or infrastructure.

Localised geological conditions and terrain as well as the trigger events (e.g. 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.

[1] In a severe triggering event, such as a large local magnitude local earthquake, landslide volumes may be much more than this volume. The most recent large triggering event was the M 8.2 Wairarapa earthquake in 1855.

3.2 SLOPE RUNOUT ASSESSMENT

The estimation of potential landslide debris runout distance and inundation area can be made by empirical or numerical (modelling) methods. Empirically based methods rely on information on the debris inundation areas of past landslides of a given type, to estimate the anticipated debris inundation area of future landslides of a similar type. Conversely, physics-based modelling methods include a range of techniques that simulate the flow of landslide material, incorporating factors like slope angle, material properties, and initial failure volume. Software tools such as DAN3D, RAMMS, or FLO-2D can be used. Physics-based methods were not used for this study as they require a large amount of data, are too time-consuming and computationally demanding to be practical for this district-wide study.

Combining empirical models with physical-based approaches and field observations can enhance the accuracy and reliability of landslide hazard predictions. Slope hazard zones developed for Tauranga City Council were derived from an empirical relationship between slope height and angle with landslide occurrence and the size of the area impacted. This was then calibrated for the volcanic ash soils within Tauranga city.

Some empirical models can include regression analysis to establish statistical relationships between landslide parameters (e.g., volume, height, and slope angle) and runout distances using regression techniques or use ratios, such as the Fahrböschung angle, to compare different landslides irrespective of their size (Dai et al., 2002; Hungr et al., 2001).

Volume-based models can be used to predict runout distances based on landslide volume. Studies have shown that larger landslides tend to travel farther, and regression equations can be developed to quantify this relationship. These models use empirical relationships derived from historical landslide data to estimate the volume based on the landslide's surface area. Common formulas include: $V=\alpha A^{\beta}$, where:

V is the volume,

A is the area, and

α and β are empirically derived constants. These relationships can vary based on landslide type and geological conditions.

One of the simplest empirical relationships is Heim's Ratio (H/L), where H is the vertical fall height, and L is the horizontal runout distance (Heim, 1932). This ratio helps estimate the travel distance based on the fall height. Another commonly used measure is the Fahrböschung angle, also known as the travel angle or shadow angle. It represents the angle between the horizontal plane and a line drawn from the highest point of the landslide scarp to the furthest point reached by the landslide debris (Hungr et al, 2001; Iverson, 1997). Lower angles indicate longer runout distances. It can be measured using $\theta=\tan^{-1}$ (H/L), where:

θ is the Fahrböschung Angle,

H is the Vertical Distance i.e. the elevation difference between the scarp and the debris runout toe, and

L is the Horizontal Distance i.e. the horizontal distance from the scarp to the debris runout toe (Figure 4).

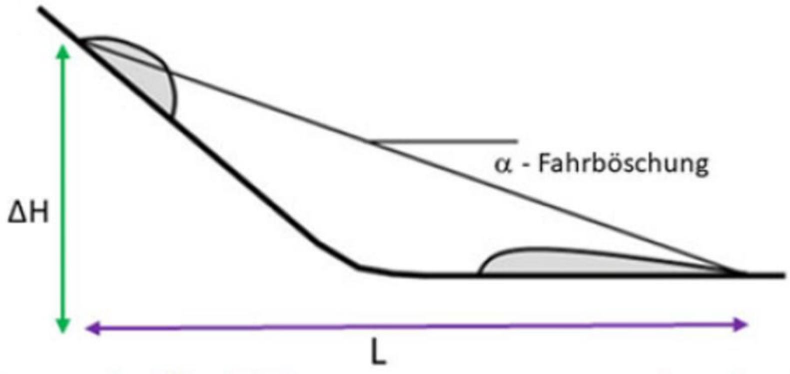


Figure 4: Schematic representation of fall height and runout distance parameters for a landslide (Brideau, et al., 2021)

The type and volume of the landslide and the characteristics of the slope in the runout path will affect the runout distance. In general, confined landslides (such as debris flows) travel further than landslides on unconfined open slopes, rainfall-triggered landslides with wet/saturated debris travelling further than landslides with dry debris of similar volumes, and larger volume landslides travel further than smaller volume landslides of the same type (Brideau et al., 2021; Iverson, 1997; Rickenmann, 1999).

In the New Zealand context, following the 2016 Kaikoura Earthquake GNS Science employed this method to determine the hazard posed to the arterial road and rail corridors by landslide debris runout (Massey et al, 2019). In this study, a number of debris flows and debris avalanches triggered by the 2016 Kaikoura earthquake were analysed to derive Fahrböschung angles for landslide volumes ranging from 1,000 to 100,000 m^3 (Table 2).

Table 2: Mean landslide source areas and Fahrböschung angles for differing landslide volumes (Massey, Lukovic, Taig, Rosser, & Ries, 2019)

Landslide Volume (m^3)	Landslide Source Area (m^2)	Fahrböschung Angle – Debris Avalanche (mean) (degrees)
1,000	715	42
5,000	2,397	38
10,000	4,034	37
20,000	8,028	35
50,000	13,511	33
100,000	22,740	31

Further research was undertaken to compile previously documented international instances of landslide runout and unpublished occurrences of landslides in New Zealand triggered by earthquakes and rainstorm events (Brideau et al., 2021). The findings were illustrated in a collection of plots depicting ΔH/L versus volume for various types of landslides, substrates, and triggering mechanisms. Debris flows and debris avalanches triggered by the 2016 Kaikoura earthquake for a range of landslide volumes and are presented in Figure 5.

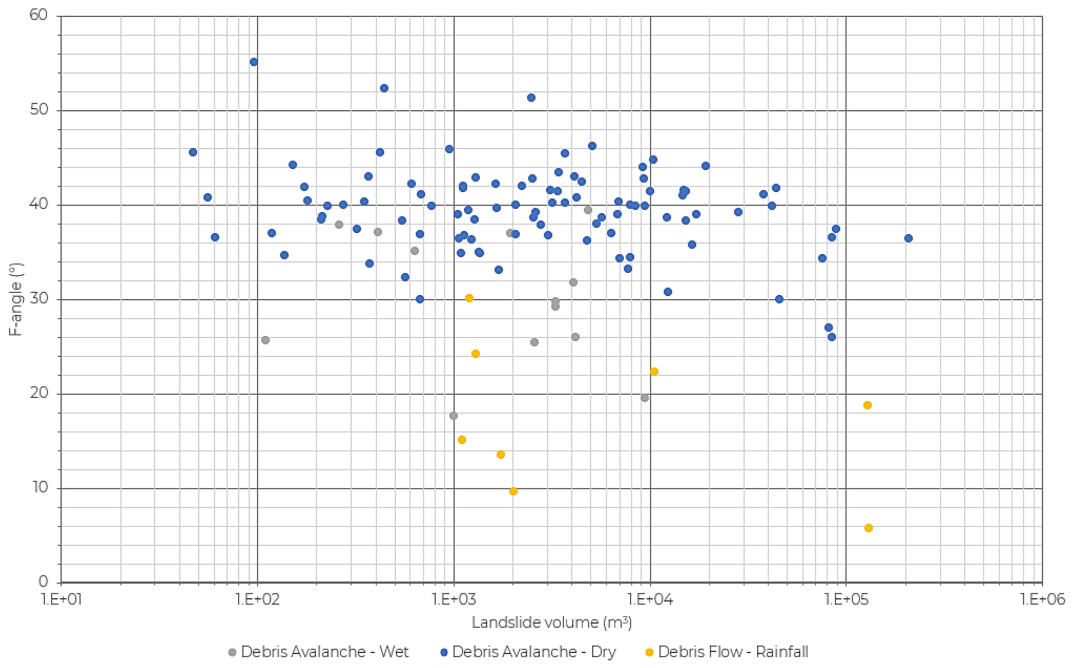


Figure 5: Fahrböschung angles for specific landslide volumes and types triggered by the Kaikoura earthquake and post-earthquake rain events (after Brideau et al., 2021)

In comparison, Figure 6 shows the range of Fahrböschung angles, for landslide volumes and types, for New Zealand landslides.

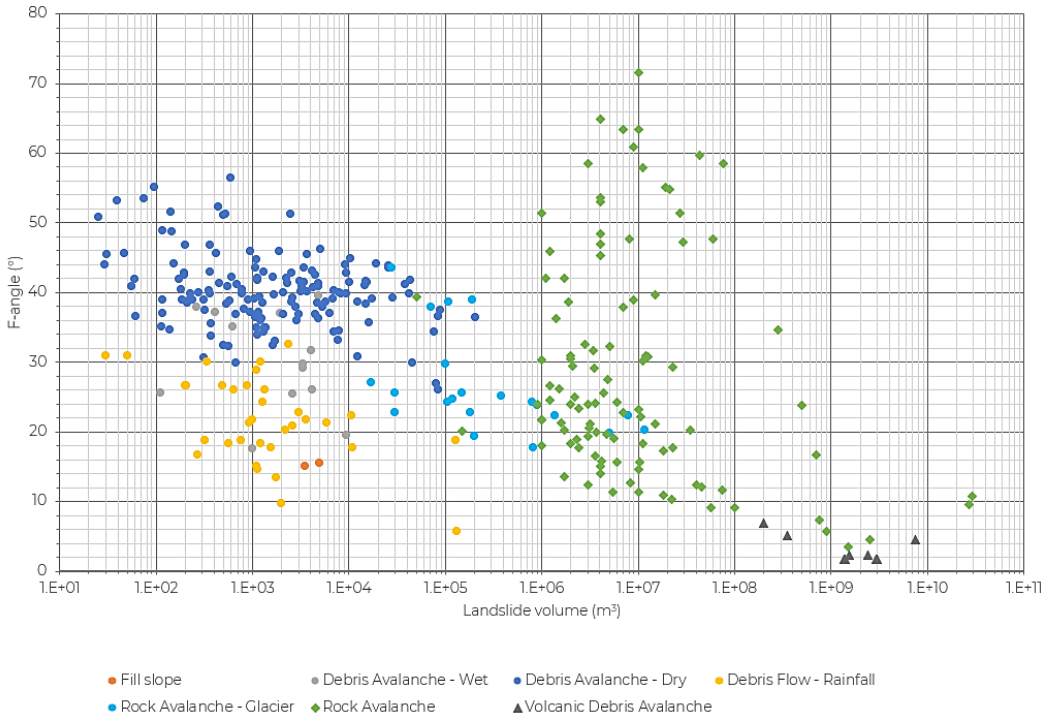


Figure 6: Fahrböschung angles for landslide volumes and types in New Zealand (after Brideau et al., 2021)

Figure 7 shows the range of Fahrböschung angles for landslide volumes and types, for worldwide examples.

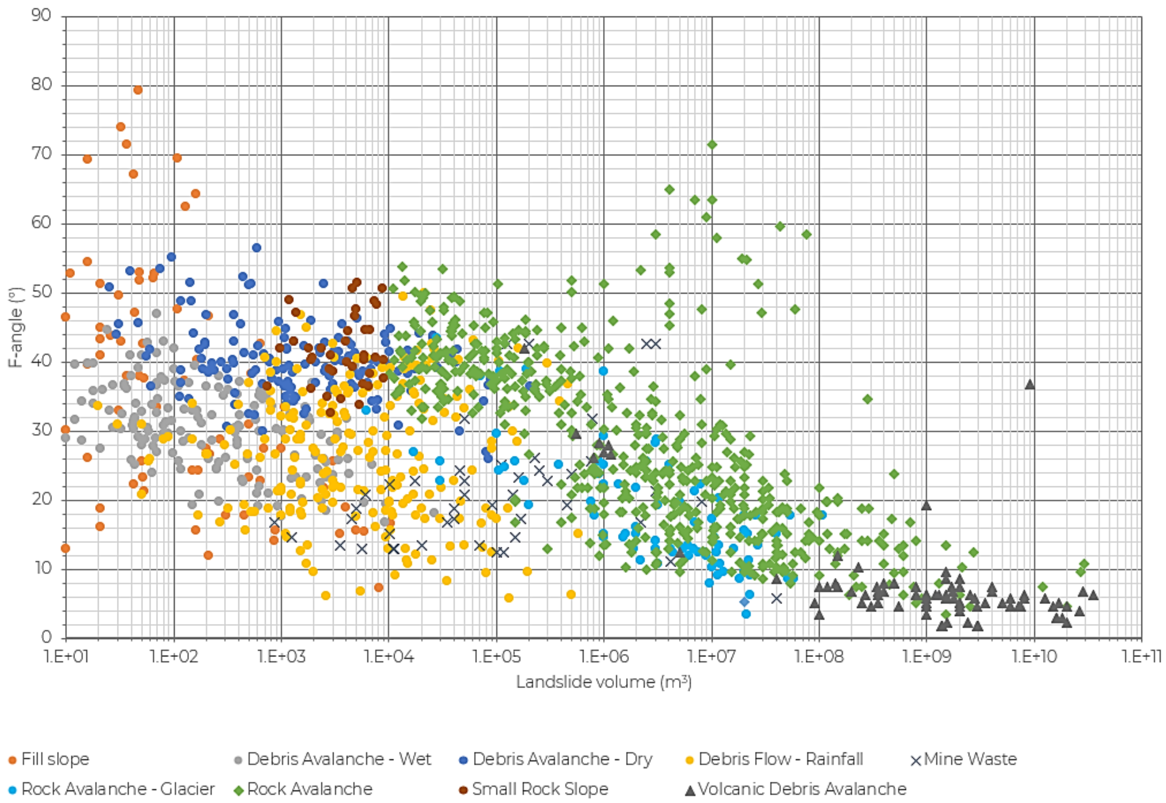


Figure 7: Fahrböschung angles for landslide volumes and types from a global database of landslides (after Brideau et al., 2021)

Applying the Fahrböschung angle in landslide runout analysis is a well-established approach in geotechnical and geological studies. Due to lack of site-specific data in the Hutt City, published Fahrböschung angles for landslides triggered by the 2016 Kaikōura earthquake (Massey et al., 2019) as well as a dataset derived from local and international literature (Brideau et al., 2021) were used to derive Fahrböschung for use in this slope runout assessment.

4 STUDY METHODOLOGY

4.1 PURPOSE

The purpose of this study is to create a landslide hazard overlay for the Hutt City district, which will identify areas that are susceptible to slope failure and/or inundation by landslide debris. This effort builds upon a previous analysis focused on slope failure susceptibility (WSP, 2021), extending it with a runout assessment.

4.2 STUDY AREA

For the purposes of this study, key activity areas have been collectively referred to as 'Focus Activity Areas' and they include the following activity areas from the District Plan:

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

These serve as the primary zones for our assessment of landslide hazards and the extent of potential slope failures and subsequent inundations (Figure 2).

4.3 DESKTOP APPRAISAL

A desktop review of the 2021 - 2024 landslide data, reports and research papers was carried out to:

- Understand where landslides have previously occurred in the study area.
- Review the characteristics of slope failure and the slope runout in the study area.
- Collect information on the methodology to undertake slope runout assessment in similar environments.

4.4 SLOPE RUNOUT ASSESSMENT

4.4.1 IDENTIFICATION OF AREAS SUSCEPTIBLE TO SLOPE FAILURE

To delineate the areas prone to landslide inundation resulting from slope instability, areas where landslides are most likely to initiate were determined. The landslide susceptibility assessment conducted in 2021 considered geology, geomorphology, and slope data to ascertain areas within the Hutt City District that are susceptible to landslides or slope failures. These analyses categorised the slope failure susceptibility from very low to very high.

Areas classified as moderate, high, or very high susceptibility to landsliding were used as landslide source areas for identifying the potential extent of runout/inundation (Figure 8). This included the following typical slope morphologies (WSP, 2021):

- Eroded Wellington Fault Scarp.
- Steep gullies and coastal cliffs, including the fringes of large gullies.
- Road cuttings.
- Residential cut and fill slopes.
- Colluvium-filled bedrock depressions.
- Smaller gullies.

For the purpose of our study, these areas are called the 'failure zones'. In some locations, such as Wainuiomata, the study areas were extended beyond the focus areas shown in Figure 2 to encompass upslope failure zones that may produce runout within the Activity Areas (Figure 8).

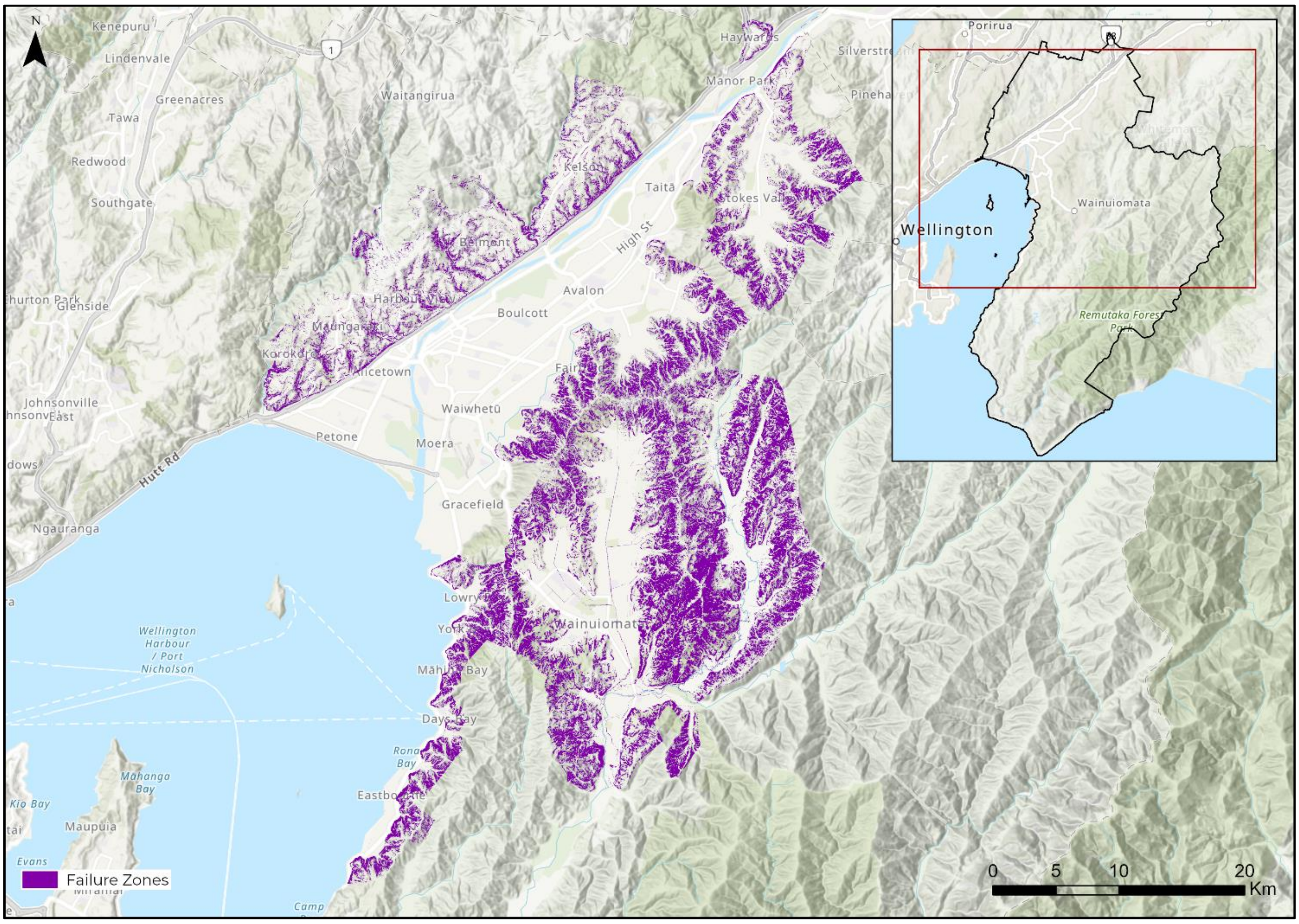


Figure 8: Failure zones in the Study Area

4.4.2 SLOPE RUNOUT ASSESSMENT AND MAPPING

Slope runout assessment using the Fahrböschung method was undertaken using the visibility tool in GIS. The visibility tool works by identifying the surface(s) that is visible to each point on the surface of the slope within the failure zones, based on a vertical parameter. This tool was used initially by Robinson (2014) in establishing horizon lines for 'observers' at defined points in the road network. The horizon lines identified slopes visible to the 'observers', signifying the landslide potential and runout (Robinson, 2014).

The 2 m Digital Elevation Model (DEM) of topography was resampled to 8 m and converted into points and clipped within the failure zones to create the 'observers'. The vertical angle parameter represented the Fahrböschung angle, which is the angle of potential runout. The land that is considered 'visible' downslope from the points within the failure zones are classified as the runout zones. Section 5.2 provides information on the Fahrböschung angle used for this study.

The GIS workflow for using the visibility tool to produce landslide runout is presented in Figure 9. Figure 10 also shows an example of the failure zones (A), observer points (B), and the output runout overlay with the failure zone (C). Information on the decision behind our choice of Fahrböschung angle can be found in Section 5.2. Using an 8 m DEM to derive the 'observers' provided a good coverage of observer points throughout the failure zones, while the runout produced was logical for what we would expect to see in the landscape when viewed at an appropriate scale.

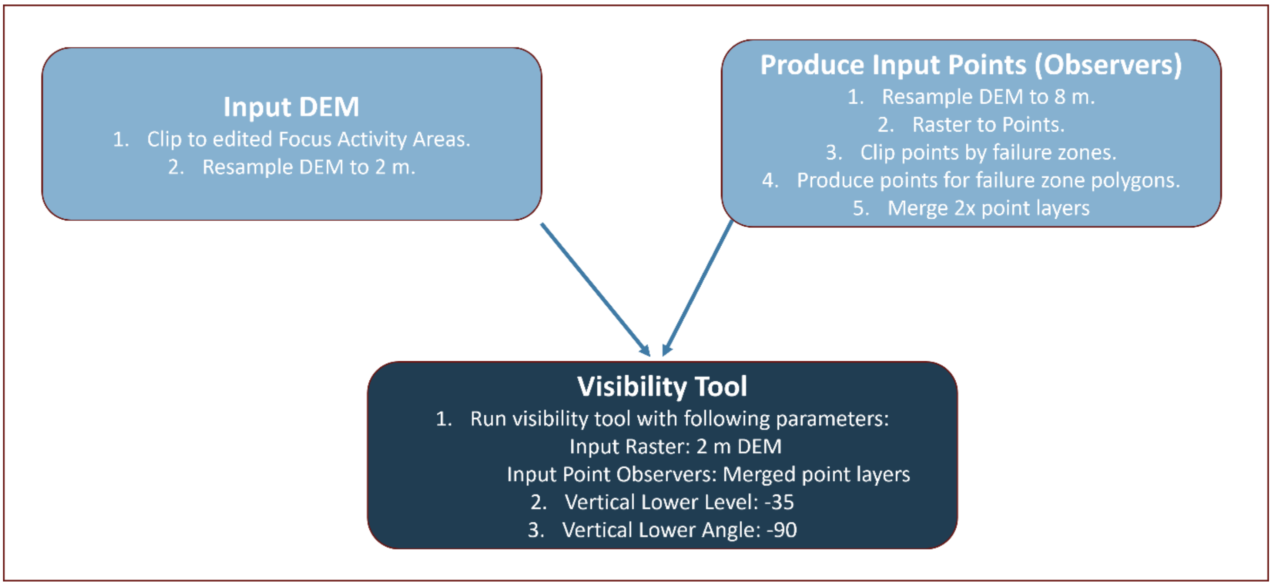


Figure 9: Flowchart showing workflow for deriving landslide runout using the visibility tool.

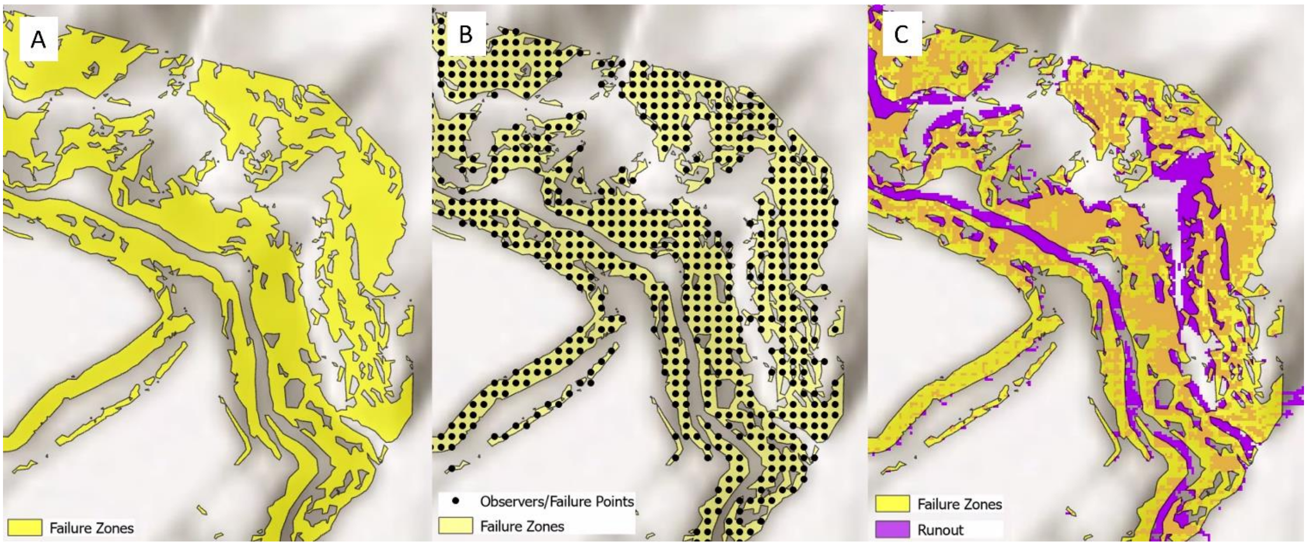


Figure 10: Example of components of runout model workflow. A shows the failure zones; B is the failure zones with observers/points overlayed, and C is the failure zones and runout.

4.4.3 VALIDATION OF SLOPE RUNOUT MODEL

In order to validate the model, a number of checks were undertaken including:

- Visual comparison of modelled landslide runout extent against the limited information held on known landslide runouts (volumes and lengths). In many cases, the modelled runout extended beyond the known runout. This is because the modelled runout includes failure initiating anywhere on the slope and/or including failure of the full slope, whereas the observed runouts were from specific events with individual characteristics that are not possible to investigate within this district-wide study.
- Geotechnical evaluation of cross section profiles developed for representative locations and slope geometries throughout the study area, to identify the terrain and the change in runout length with differing vertical angles.

4.5 MAPS

The combined slope failure and runout overlay, and the runout zones for the Hutt City district are presented at 1:15,000 scale in Appendix A and B.

4.6 REPORTING

This technical report was prepared to present the methodology, results and limitations of the slope hazard mapping.

5 SLOPE RUNOUT ASSESSMENT

5.1 OUTLINE

A slope runout assessment was undertaken for Council and has been mapped in GIS resulting in slope runout zones outlining areas considered susceptible to impact from landslide debris, including soil and rock, from failures or movement of upslope instability. The slope runout assessment was only undertaken within and adjacent to residential activity areas (excluding rural residential) identified in the district plan, and are displayed in Figure 2.

5.2 SELECTION OF F-ANGLE & ASSUMPTIONS

For the slope runout assessment, we utilised a Fahrböschung angle of 35° as the vertical parameter to represent the potential runout angle for all failure source zones. We acknowledge that the Fahrböschung angle can vary depending on slope heights, substrates, and trigger mechanisms such as earthquakes or storms. However, for a district-wide slope runout assessment, we consider a Fahrböschung angle of 35° to be representative of various landslide types and volumes within the Hutt City district.

Figures 4 and 5, along with Table 2 in Section 3.2, provide detailed information on the range of Fahrböschung angles observed in New Zealand and globally for landslides of different volumes (Massey et al., 2019; Brideau et al., 2021). According to Table 2, a Fahrböschung angle of 35° corresponds to a representative landslide volume of 20,000 m^3. This volume is smaller than what we anticipate for many of the landslides within our study area. However, when looking at Figures 4 – 6, there is variability in the Fahrböschung angle and associated volumes. While representing a volume of 20,000 m^3 in the Massey et al study (2019), 35 ° provides a representation across different landslides types.

While a Fahrböschung angle of 35° may be considered conservative for dry rockfalls, most landslides in our study area are likely triggered by rainfall. Although 35° might be less conservative for saturated, rainfall-induced landslides, our local knowledge indicates that landslides in the region are primarily caused by intense rainfall rather than prolonged saturation. Thus, by selecting a Fahrböschung angle of 35°, we account for both triggers and consider the presence of both rock and soil components in the landslides.

Our assessment focuses solely on debris avalanches, which include landslides comprising boulders, other debris, or rockfall. We did not consider debris flows, which typically have a shallower Fahrböschung angle and result in longer runout distances.

Further limitations of our study, including limitations surrounding the data resolution used in the study, are discussed in Section 5.5.

5.3 ASSESSMENT

To complete the slope runout assessment, we used the methodology outlined in Section 4.4 with a Fahrböschung angle of 35° as the vertical parameters.

5.4 MAPS

The combined slope failure and runout overlay, and the runout zones for the Hutt City district are presented at 1:15,000 scale in Appendix A and B.

Maps of the combined slope failure (incorporating the landslide susceptibility zones from the 2021 WSP study) and runout zones are provided at a scale of 1:15,000 in Appendix A. Maps of the failure and runout zones are provided at a scale of 1:15,000 in Appendix B.

5.5 LIMITATIONS

The slope runout assessment and slope instability overlays have been produced at a city-wide scale using a desk-based approach with terrain data in a GIS platform. Limitations associated with this mapping are discussed below.

5.5.1 SCALE OF MAPPING

No site-specific data or analysis has been incorporated into the mapping of the slope runout. The mapping has been completed as part of a city-wide study, and the maps should not be used at scales greater than 1:5,000, or for site-specific assessments. Ideally, the maps should not able to be viewed at larger scales, but if the zones are able to be visualised at larger scales than this, such as for individual properties, then a disclaimer should be included, potentially as overlay text on the map.

5.5.2 DATA RESOLUTION

Assessment and mapping of the zones will have inherent uncertainties, but these were mitigated by the use of high-resolution LiDAR terrain data, and sensitivity checked.

WSP's previous landslide susceptibility study (WSP, 2021) was produced at a 1 m pixel resolution. In order to facilitate efficient processing of the terrain data for this study of runout assessment, the pixel resolution was resampled to 2 m and points used for the initiation of slope failures within the failure zones were captured at 8 m resolution. Small failure area polygons (i.e. smaller than 8 m x 8 m dimensions) were sampled using the polygon to point tool to ensure each failure area was represented in the runout assessment.

5.5.3 DATA QUALITY

The runout overlay produced should not be regarded as a static layer. Updated or higher quality datasets, and improved mapping of known landslips can improve landslide runout knowledge and refine the overlay.

5.5.4 LANDSLIDE RUNOUT INVENTORY

There is limited information on landslide runout volumes and extent within Hutt City. The landslide inventory used in the previous stage of this study was primarily a point dataset, with most input data also being points, or being areas showing a full extent of a landslide (i.e. the failure and runout zones). The inclusion of residential landslides into the landslide inventory included runout volumes up to 83 m^3. Due to the nature of reporting, the volume was not always recorded and therefore estimated based on topography, site notes and photographs. Only a small number of landslides with an estimated failure zone were available.

5.5.5 LANDSLIDE TYPE

As previously discussed, we have excluded any landslide runout that may be produced from debris flows. The angle of runout for debris flows would be shallower than 35 ° and runout would be significantly further than that of a debris avalanche. As overland flow path and flood data was not available within the study period, it was decided by council to exclude this from the assessment and reporting.

5.5.6 LANDSLIDE VOLUME

The volume of potential failures has not been considered as part of this study. The factors that determine the volume and runout characteristics of the landslide, and the consequent impacts on infrastructure in proximity to the slope, could be considered when looking at specific slopes as part of site-specific studies. This should be carried out as part of considering the risk posed to infrastructure or property at particular sites.

5.5.7 LOW HEIGHT SLOPES

Low height slopes (up to ~4 m) have not been captured in the slope runout assessment as it was not practical within the scope of the study to capture all of the individual, small scale slope features. These slopes generally consist of individual cut/fill slopes or natural slopes such as stream banks.

5.5.8 ENGINEERED OR MODIFIED SLOPES

There are engineered and treated slopes in Hutt City, including cuttings, fills, and retaining structures built during residential development and as part of road and rail networks. The available terrain and property information used for mapping of the runout zones does not differentiate engineered slopes from unsupported slopes, and the city-wide nature of the study makes it impractical to assess whether each individual slope has been engineered and the standards to which the slope has been designed. Consequently, we have not been able to differentiate engineered slopes and therefore all slopes would have been assessed as non-engineered slopes.

5.5.9 RECENT GROUND LEVEL CHANGES

WSP's landslide susceptibility study (WSP, 2021) has formed the basis of this study, with the moderate – very highly susceptible zones forming the failure zones for the runout assessment. This original 2021 study included elevation data captured in 2013-2016. Earthworks associated with subdivision and land development and changes in ground level that occurred after the capture of the elevation data will not be reflected in the zones. We recommend that input landslide susceptibility study or failure zones are reviewed periodically to incorporate new elevation data, which will allow for the results to be updated.

6 GIVING EFFECT TO THE PROJECT

6.1 THE DISTRICT PLAN

The District Plan serves as the primary guide for overseeing land use and development within a city. Since 2004, the Council has operated under its current District Plan, which includes objectives, policies, and rules to address various resource management issues. Recently, a comprehensive review and revision of this plan have been completed, with a draft version made available for public feedback in late 2023. The proposed District Plan is expected to be open for formal submissions later in 2024.

To manage the risk of slope failures to property and life in the Hutt City district, different controls on activities and development should be implemented in the District Plan.

6.2 OPTIONS FOR PLANNING CONTROLS

The slope failure susceptibility maps from WSP's 2021 study and the slope failure runout maps, and the combined landslide susceptibility zone overlays appended to this report, 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.

6.2.1 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 of higher slope failure susceptibility or within a slope debris runout zone. If development is to occur in these areas, then this should be for low-intensity development only. Areas of lower susceptibility to landslide impacts should be used for high-intensity development.

Development in areas of lower slope failure susceptibility, or associated slope failure runout zone, may be acceptable when developing new subdivisions and buildings, as engineered measures can be implemented to mitigate the risk to the development through improvement in stability of slopes or protection from runout. Before considering such mitigation measures, there should be a thorough process of geotechnical investigation and analyses to assess the site-specific slope stability conditions.

6.2.2 CONTROL 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.

6.2.3 GEOTECHNICAL ASSESSMENTS OF SLOPE STABILITY

Where land is considered susceptible to slope failures and slope runout (i.e. land represented by the landslide susceptibility overlay), the requirement for a geotechnical assessment by a suitably qualified and experienced geotechnical engineer can be implemented as a control by the 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, with particular experience in assessing slope stability and the consequences of slope failure.

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 lifeline infrastructure, property and life, under these guidelines.

6.2.3.1 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, and the WSP 2021 report, classify the land in terms of the susceptibility to slope failure and identifies areas that may be inundated by debris runout from slope failure (i.e. slope runout). These maps can form the basis for development control.

6.2.3.2 PROVISION OF SLOPE INSTABILITY INFORMATION

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, slope runout and the existence of past landslides within the Land Information Memorandum (LIM) reports for individual properties.

6.2.4 LAND USE PLANNING

The landslide susceptibility overlay maps should be used to inform land use planning, urban growth strategies and plan change proposals to ensure that areas zoned for future development do not create landslide risk 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.

6.2.5 OTHER USES OF MAPS

The slope instability overlay 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. These hazard maps can be used to assess the resilience of infrastructure, particularly lifelines and the built environment as a whole.

The Council's civil defence and emergency management groups will also benefit from these hazard maps, and the resilience and risk assessments based on the hazard maps.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

A slope runout assessment was undertaken for Council and has been mapped in GIS resulting in slope runout zones outlining areas considered susceptible to impact from landslide debris, including soil and rock, from failures or movement of upslope instability. The slope runout assessment was only undertaken within and adjacent to focus areas which include residential activity areas (excluding rural residential) identified in the district plan.

These slope runout zones were combined with slope failure susceptibility to provide an overall slope instability overlay that can be used in the District Plan. The slope runout zones have been mapped at a scale of 1:5,000. Maps of the runout zones and the landslide susceptibility overlay are provided in Appendix A and B at a scale of 1:15,000.

7.2 RECOMMENDATIONS

Based on the results of the study, we make the following recommendations for consideration.

APPLICATION OF THE OUTPUTS OF THE STUDY

1. The landslide susceptibility overlay maps are included in the District Plan and used by Council for resource and building consenting processes.
2. The landslide susceptibility overlay maps are used with reference to this report.
3. The landslide susceptibility overlay maps are used at a scale no greater than 1:5,000, and ideally are not able to be displayed at larger scales. A disclaimer should be included that the maps should not be displayed or considered at a larger scale, potentially as overlay text on the map.
4. The landslide susceptibility overlay maps are reviewed periodically as new elevation and geotechnical data for the city is collected, and updated in areas where there is new information.
5. The landslide susceptibility overlay maps are used for emergency response planning by lifeline utility owners and Council's civil defence and emergency management groups to plan their response.

OPPORTUNITIES FOR FURTHER ENHANCEMENT

6. Ongoing data collection and geotechnical investigations are implemented, to improve understanding of the distribution, impacts and controlling factors of landsliding across Hutt City. Such measures could include:
    - A programme of landslide data collection for Council maintenance staff to capture systematic and regular records of failures as they occur. The data captured could include information on the location, extent, type and volume of failure, using data capture tools (e.g., Survey123, Mobile Road, Pocket RAMM).

- Periodic investigation of individual landslides, to advance the understanding of the ground and groundwater conditions at the time of failure and following failure (using instrumental monitoring). This should include assessment and documentation of relationships between the failure mechanism, landslide volume, and runout characteristics. Collection of instrumental data would allow for better correlation with rainfall and seismic data, to improve the understanding of slope behaviour in relation to these triggers.

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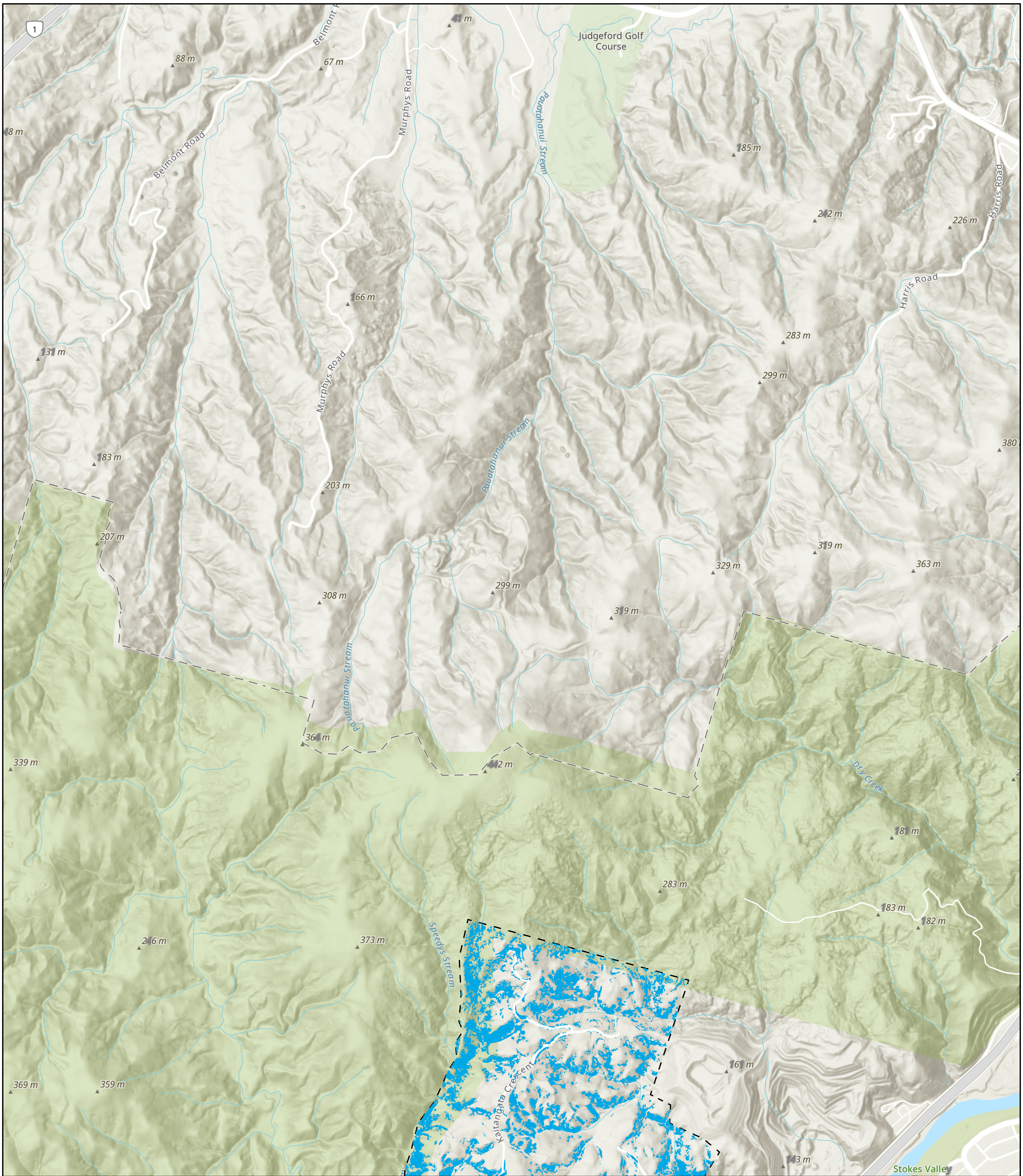
APPENDIX A

COMBINED LANDSLIDE FAILURE AND RUNOUT OVERLAY



Landslide Susceptibility Zones for District Plan
Combined Failure and Runout Zones

Prepared For: HUTT CITY TE AWA KAIRANGI

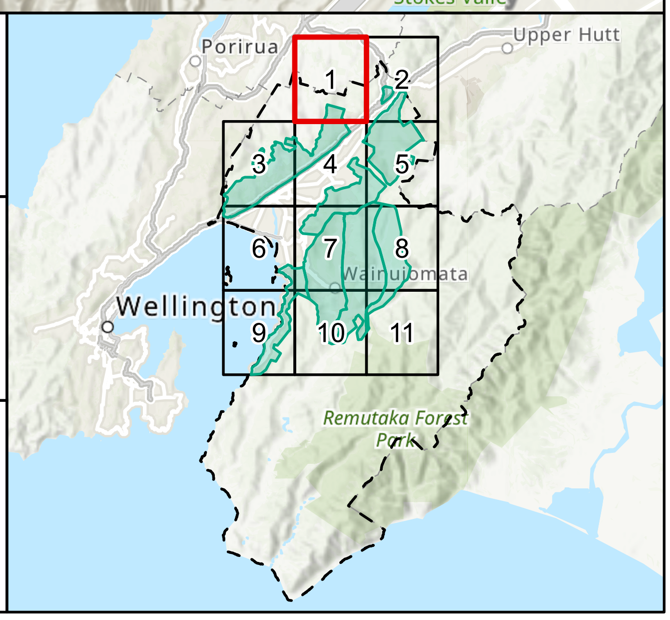
Scale: 0 250 500 1,000 Meters

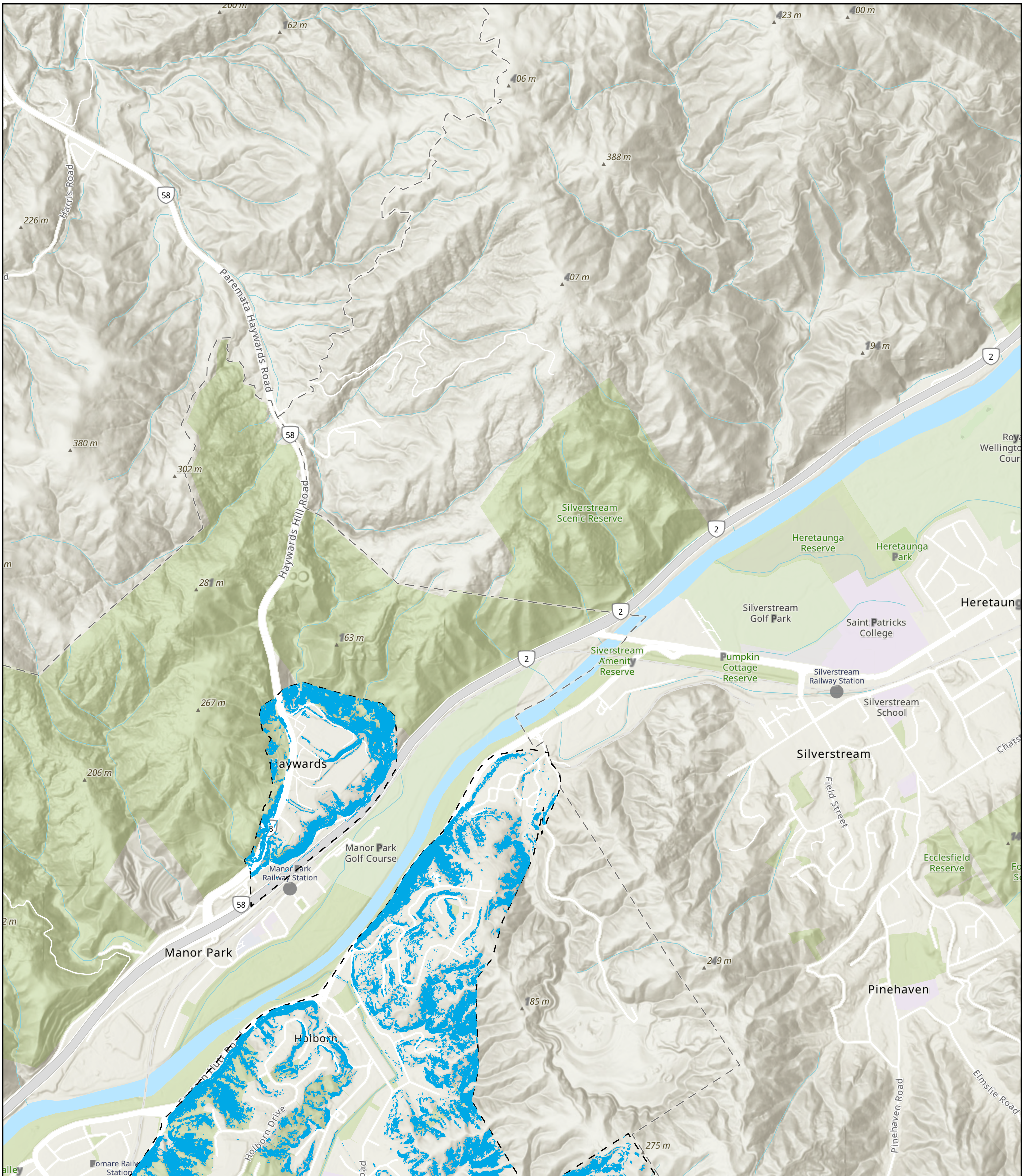
Prepared By: wsp

Date: 07/06/2024

Project: 5-C4307.01

Legend:
- Focus Activity Areas
- Combined Failure and Runout





Landslide Susceptibility Zones for District Plan

Combined Failure and Runout Zones

Prepared For: HUTT CITY TE AWA KAIRANGI

Prepared By: WSP

Scale:

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Meters

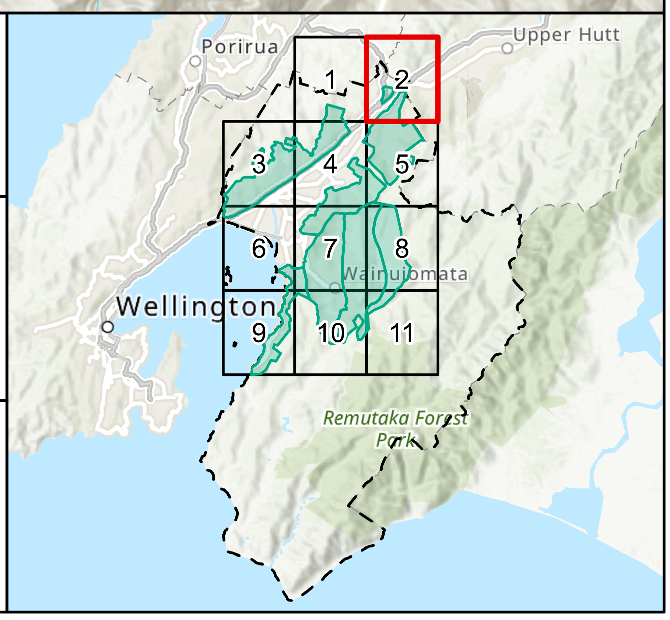
Date: 07/06/2024

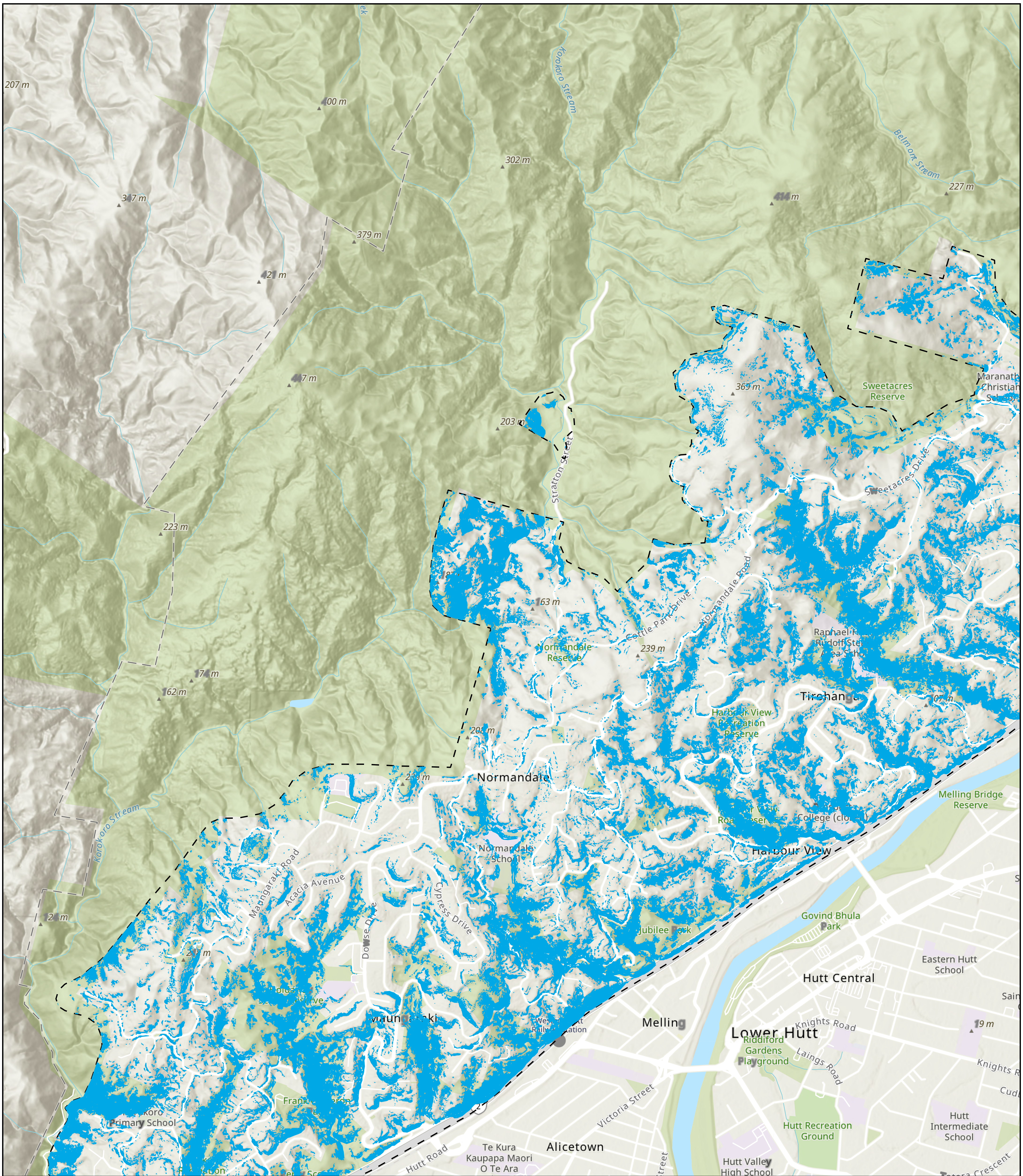
Project: 5-C4307.01

Legend:

Focus Activity Areas

Combined Failure and Runout





Landslide Susceptibility Zones for District Plan

Combined Failure and Runout Zones

Prepared For: HUTT CITY TE AWA KAIRANGI

Prepared By: wsp

Scale:

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Meters

Date: 07/06/2024

Project: 5-C4307.01

Legend:

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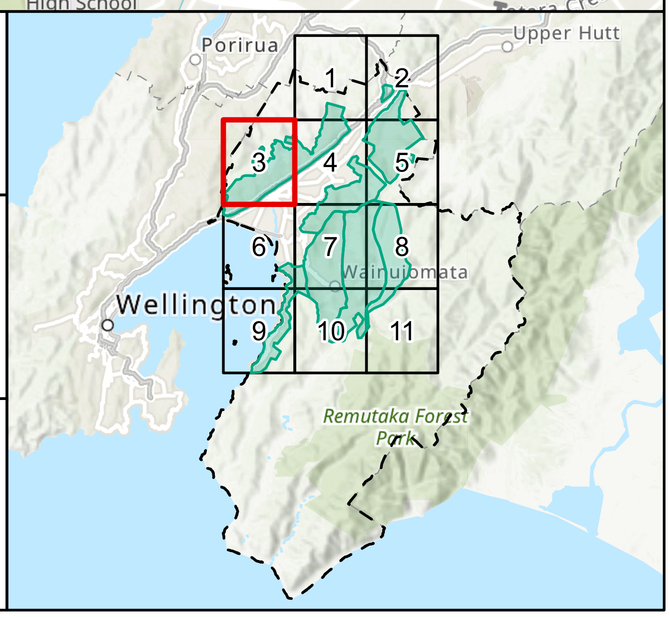
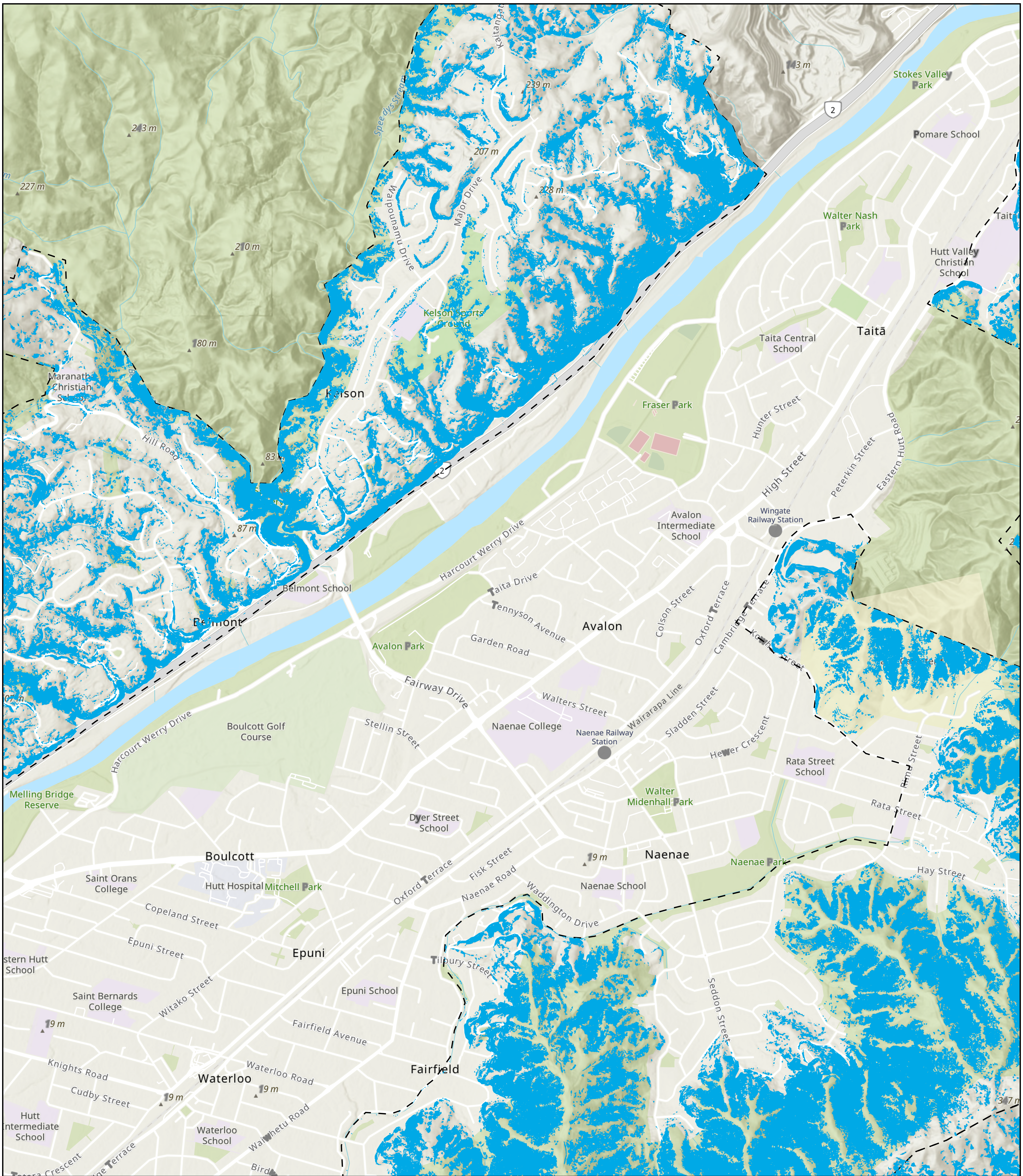
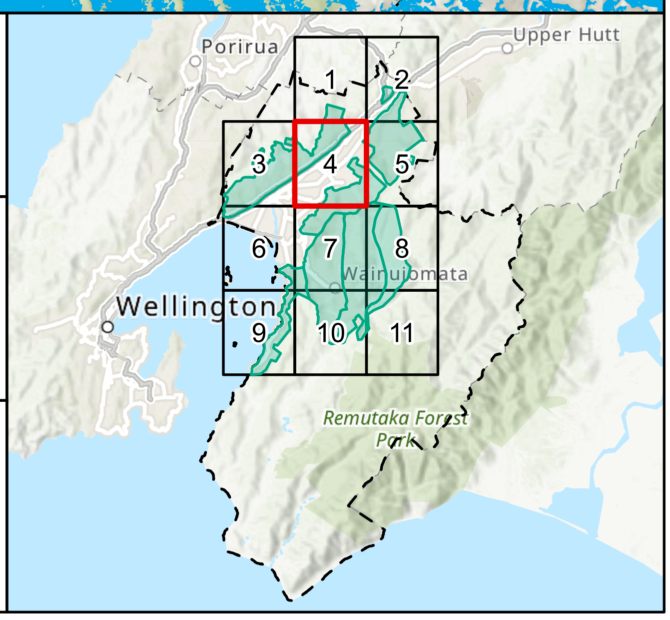
- Combined Failure and Runout







Landslide Susceptibility Zones for District Plan

Combined Failure and Runout Zones

Prepared For: HUTT CITY TE AWA KAIRANGI

Prepared By: wsp

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Project: 5-C4307.01

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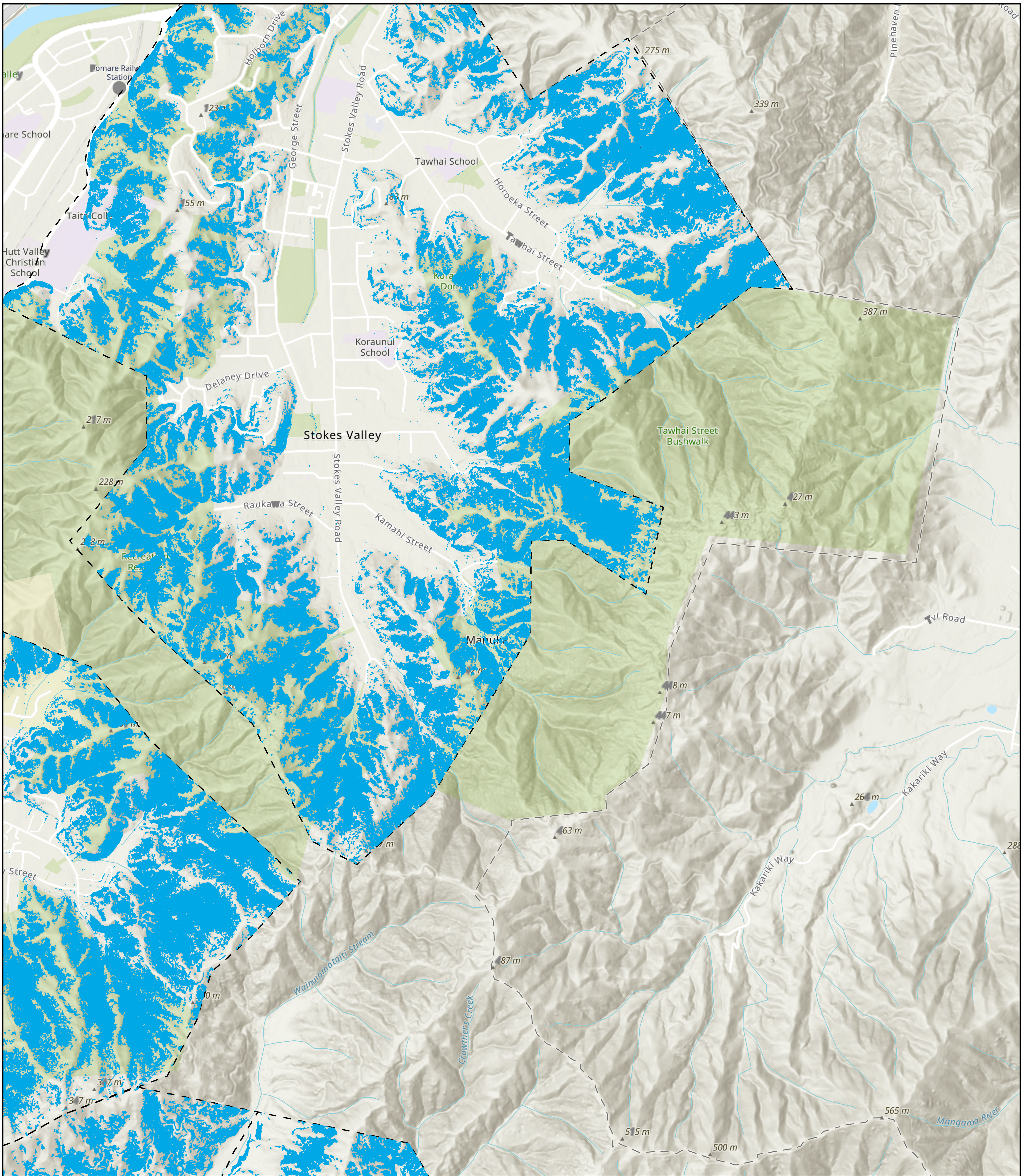

Landslide Susceptibility Zones for District Plan

Combined Failure and Runout Zones

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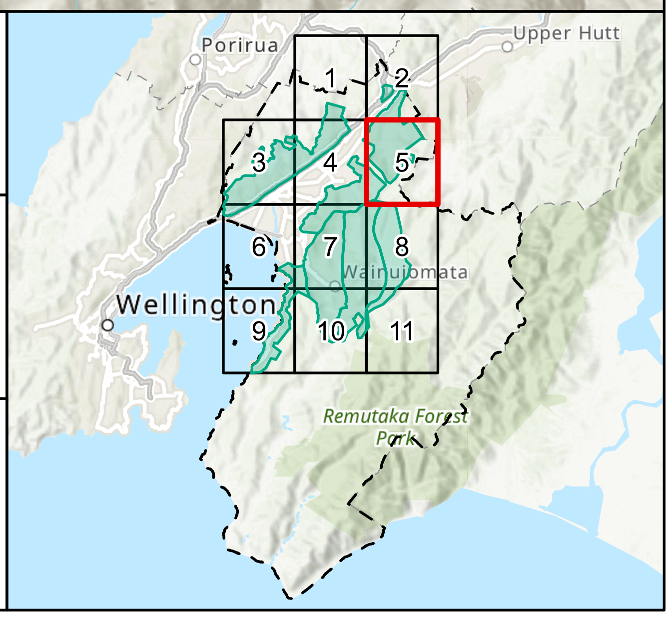
Legend:

Focus Activity Areas

Combined Failure and Runout



Landslide Susceptibility Zones for District Plan

Combined Failure and Runout Zones

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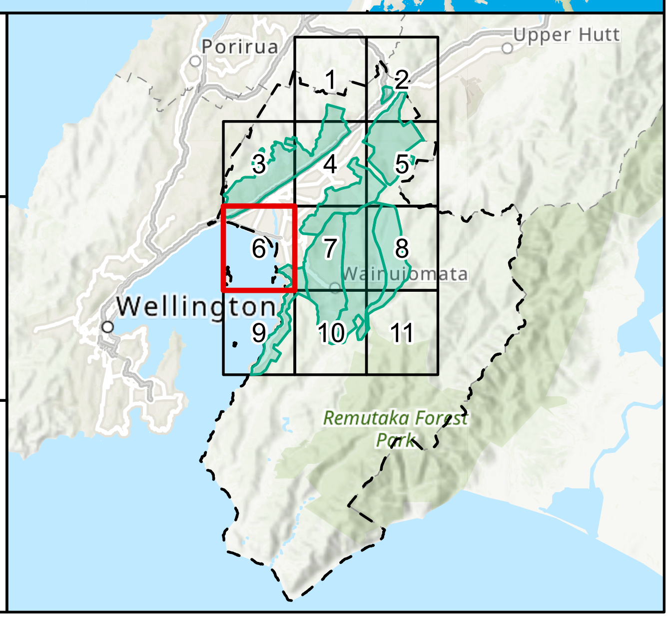
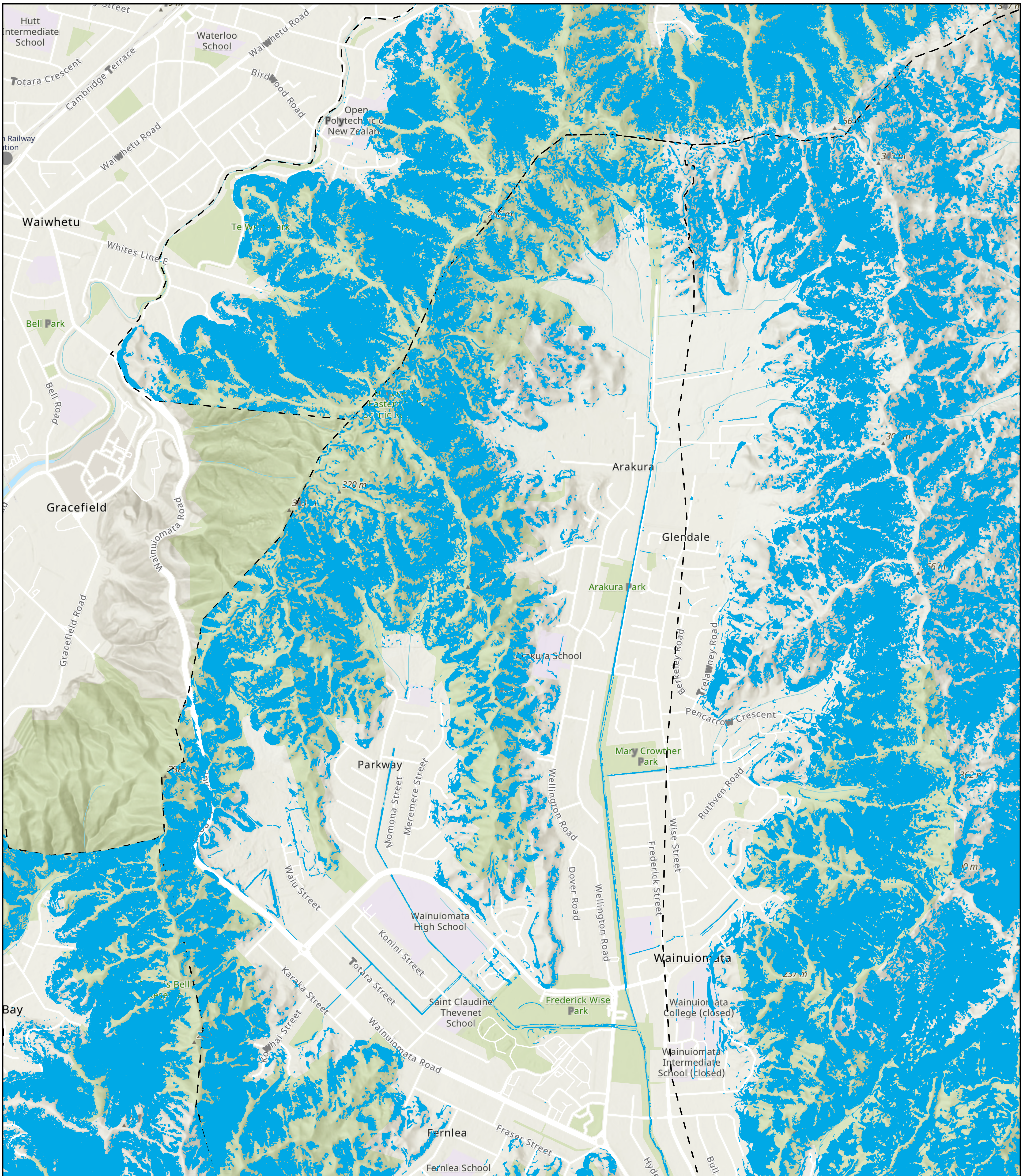
Focus Activity Areas

Combined Failure and Runout





Landslide Susceptibility Zones for District Plan

Combined Failure and Runout Zones

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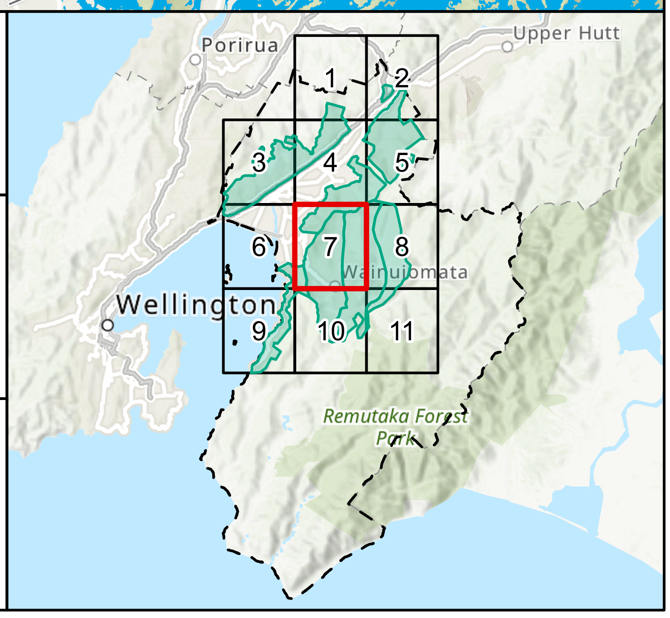
- Combined Failure and Runout



Landslide Susceptibility Zones for District Plan

Combined Failure and Runout Zones

Prepared For: HUTT CITY TE AWA KAIRANGI

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Meters

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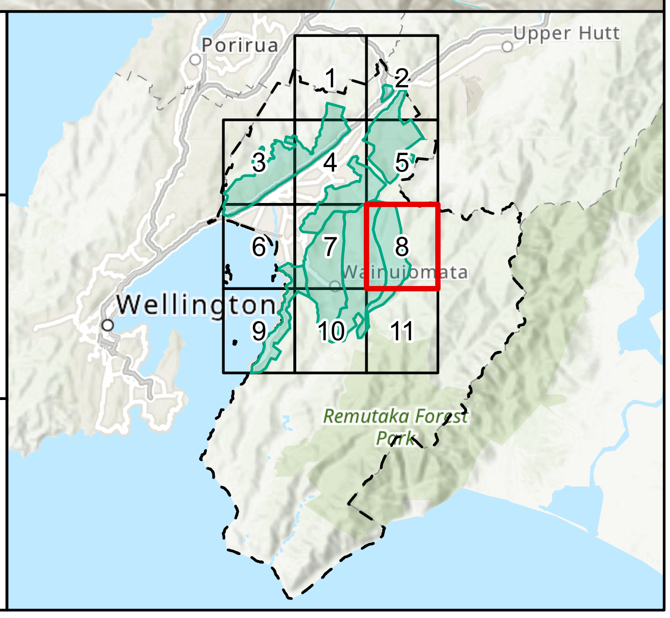
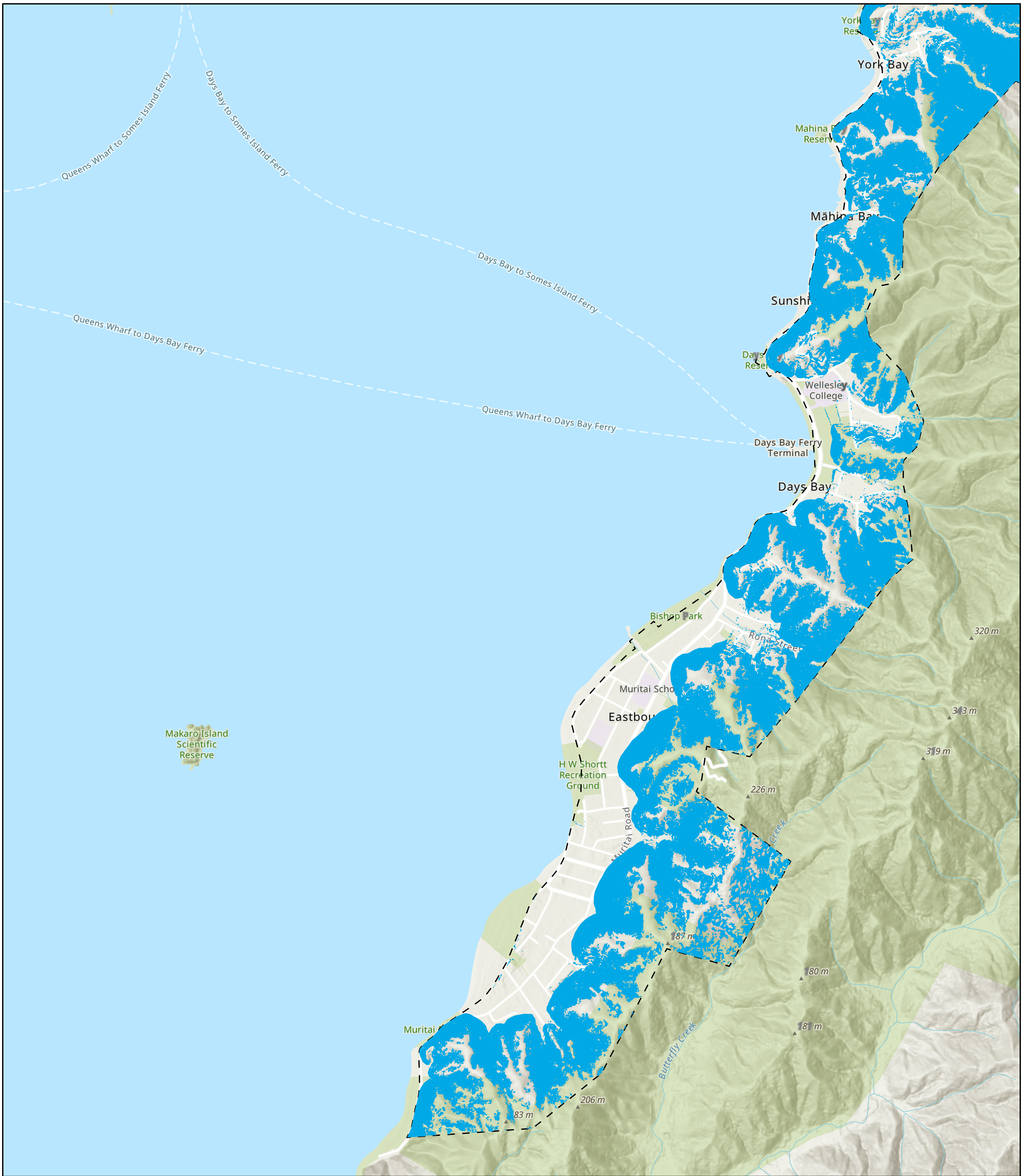
Legend:

Focus Activity Areas

Combined Failure and Runout





Landslide Susceptibility Zones for District Plan

Combined Failure and Runout Zones

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Legend:
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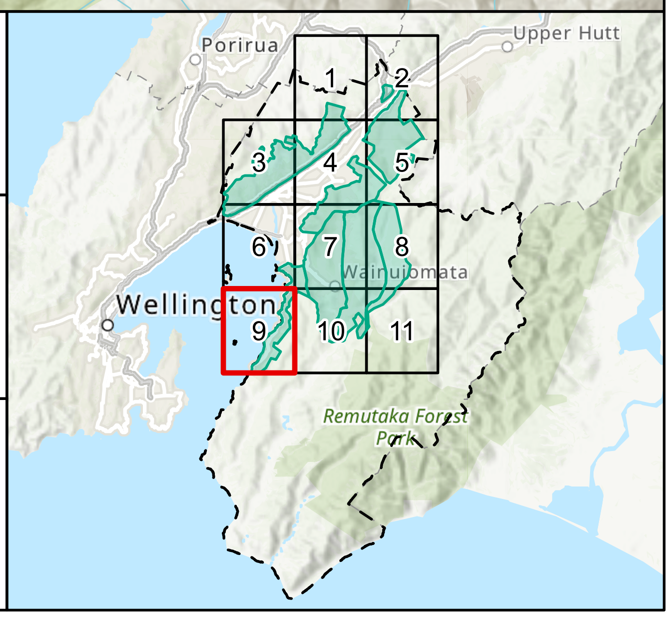
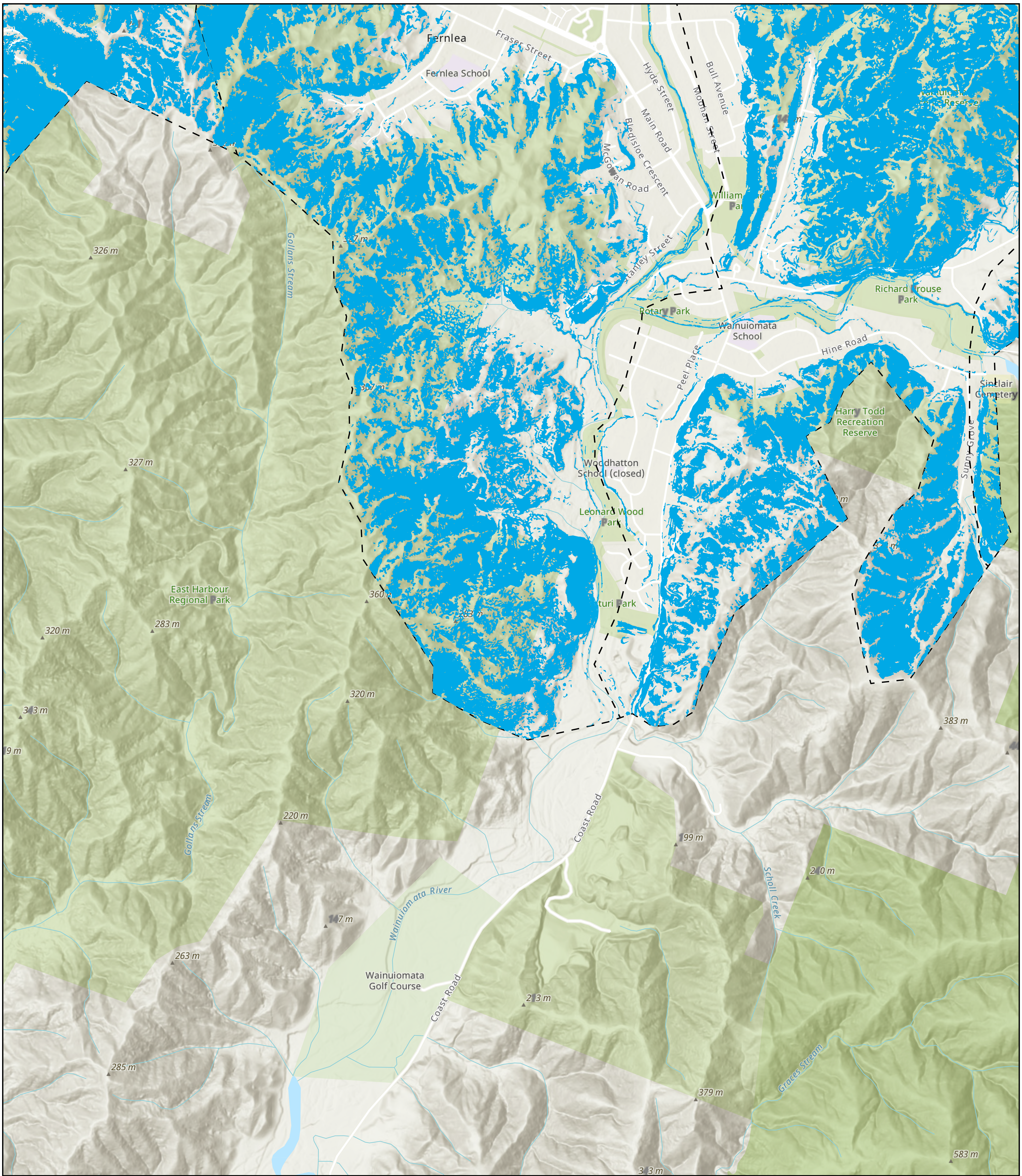




Landslide Susceptibility Zones for District Plan

Combined Failure and Runout Zones

Prepared For: HUTT CITY TE AWA KAIRANGI

Scale: 0 250 500 1,000 Meters

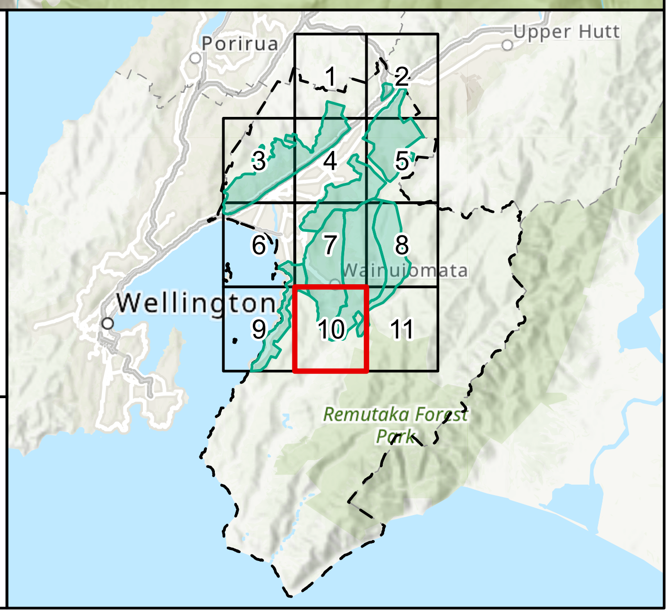
Prepared By: WSP

Date: 07/06/2024

Project: 5-C4307.01

Legend:

- Focus Activity Areas
- Combined Failure and Runout



Landslide Susceptibility Zones for District Plan
Combined Failure and Runout Zones

Prepared For: HUTT CITY TE AWA KAIRANGI

Scale:
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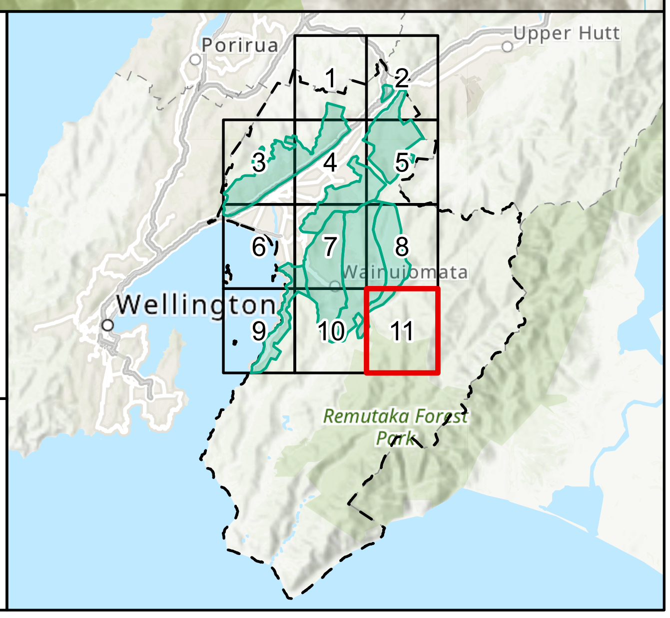
Meters

Prepared By: wsp

Date: 07/06/2024

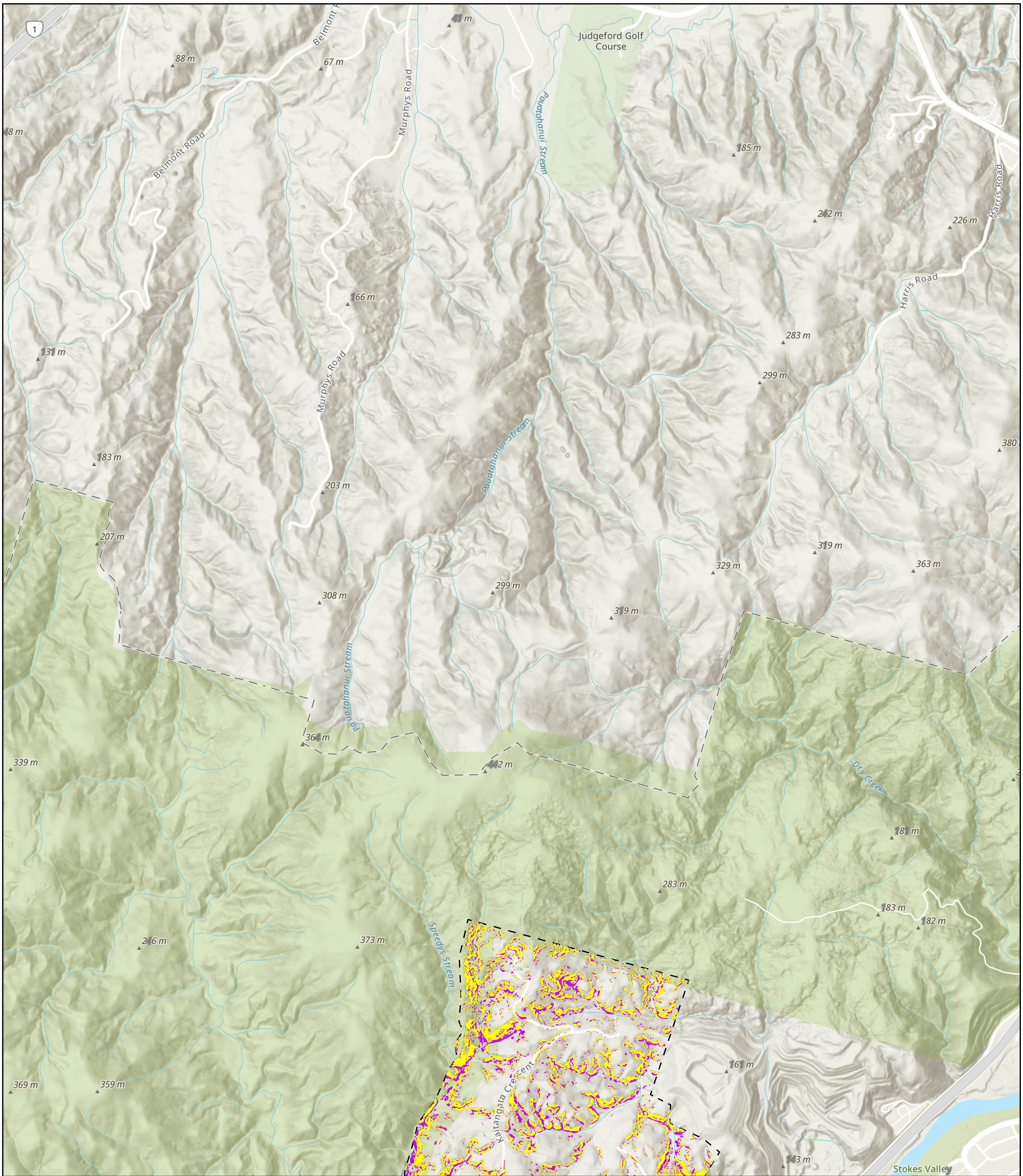
Project: 5-C4307.01

Legend:
Focus Activity Areas
Combined Failure and Runout



APPENDIX B

FAILURE AND RUNOUT ZONES



Landslide Susceptibility Zones for District Plan

Failure and Runout Zones

Prepared For: HUTT CITY TE AWA KAIRANGI

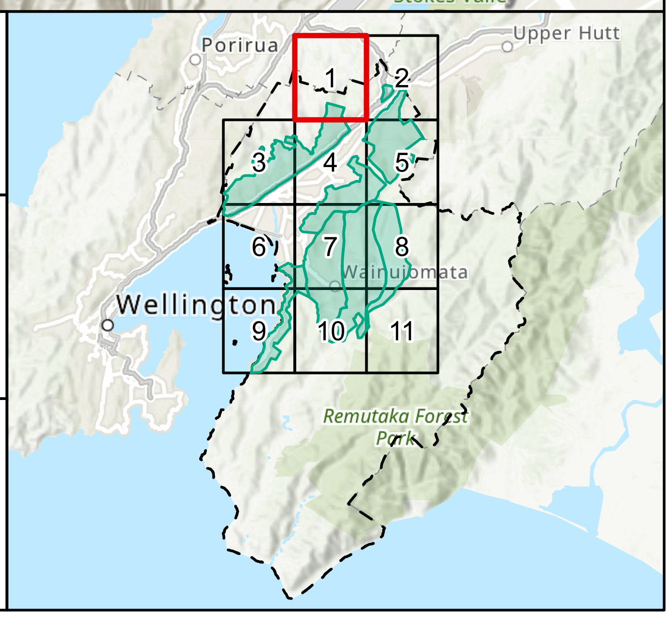
Prepared By: wsp

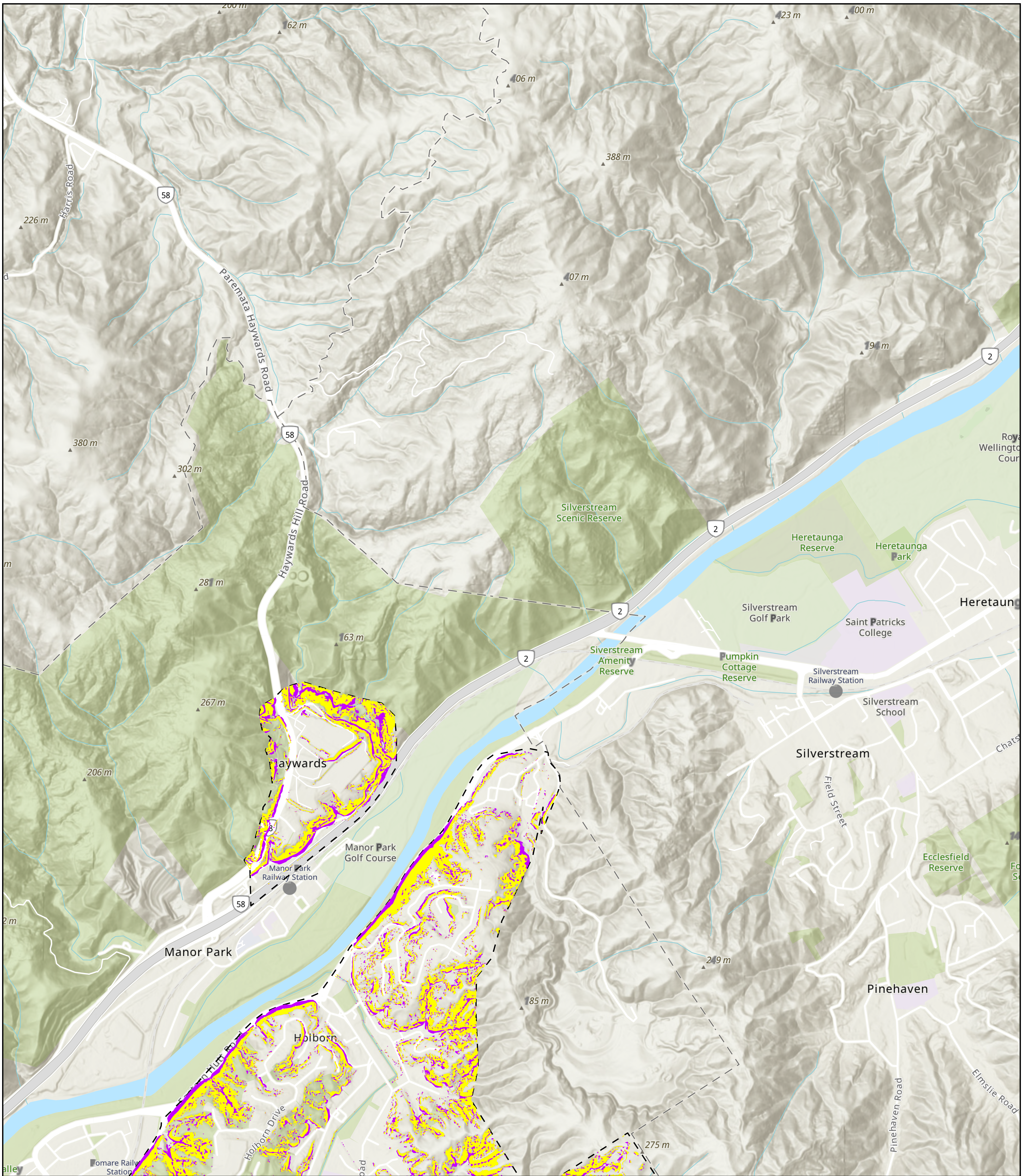
Scale: 0 250 500 1,000 Meters

Date: 07/06/2024

Project: 5-C4307.01

Legend:
- Failure Zones
- Runout Zones
- Focus Activity Areas





Landslide Susceptibility Zones for District Plan

Failure and Runout Zones

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Scale:

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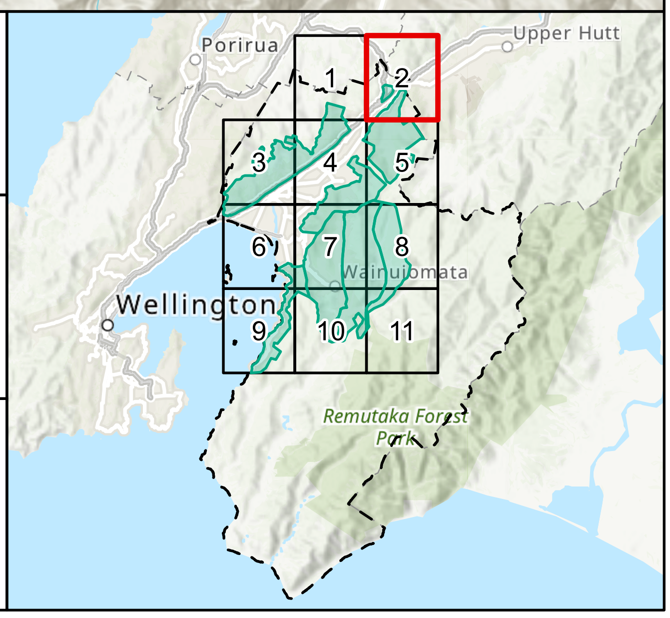
Meters

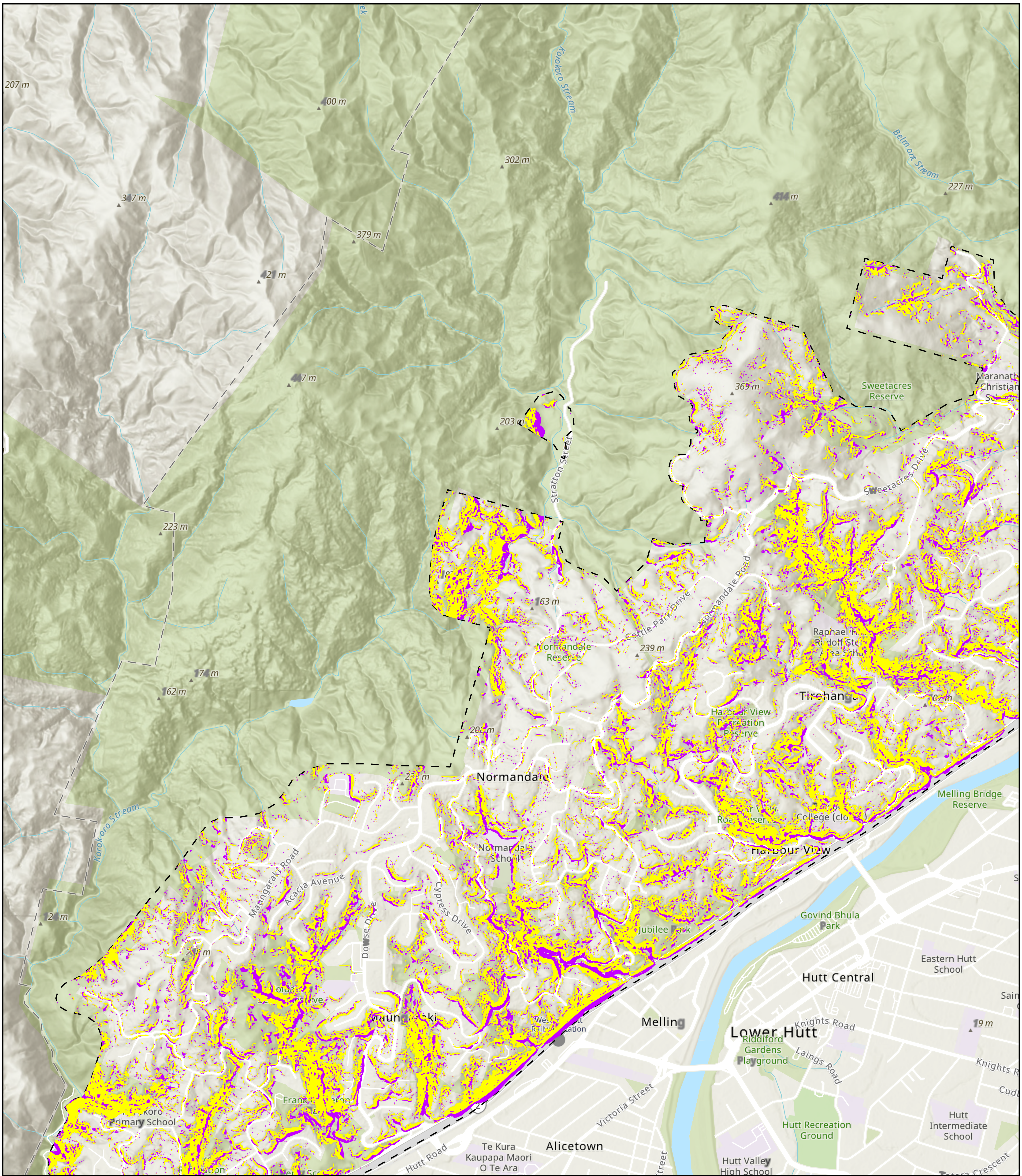
Date: 07/06/2024

Project: 5-C4307.01

Legend:

- Failure Zones
- Runout Zones
- Focus Activity Areas





Landslide Susceptibility Zones for District Plan

Failure and Runout Zones

Prepared For: HUTT CITY TE AWA KAIRANGI

Prepared By: wsp

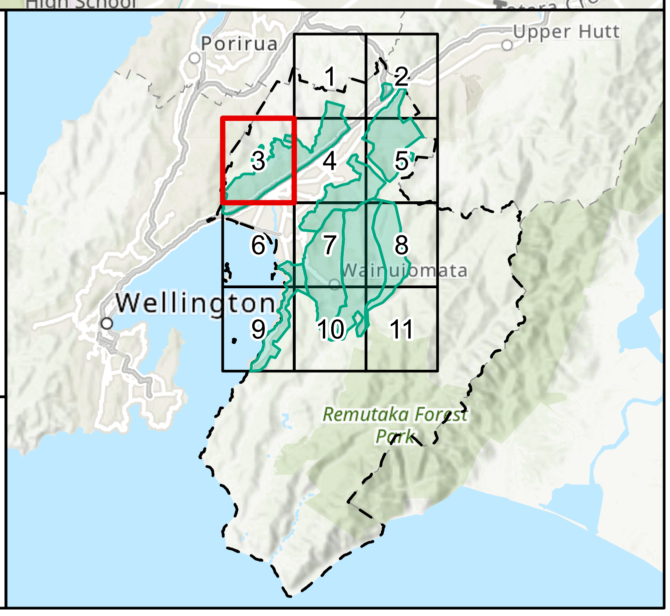
Scale: 0 250 500 1,000 Meters

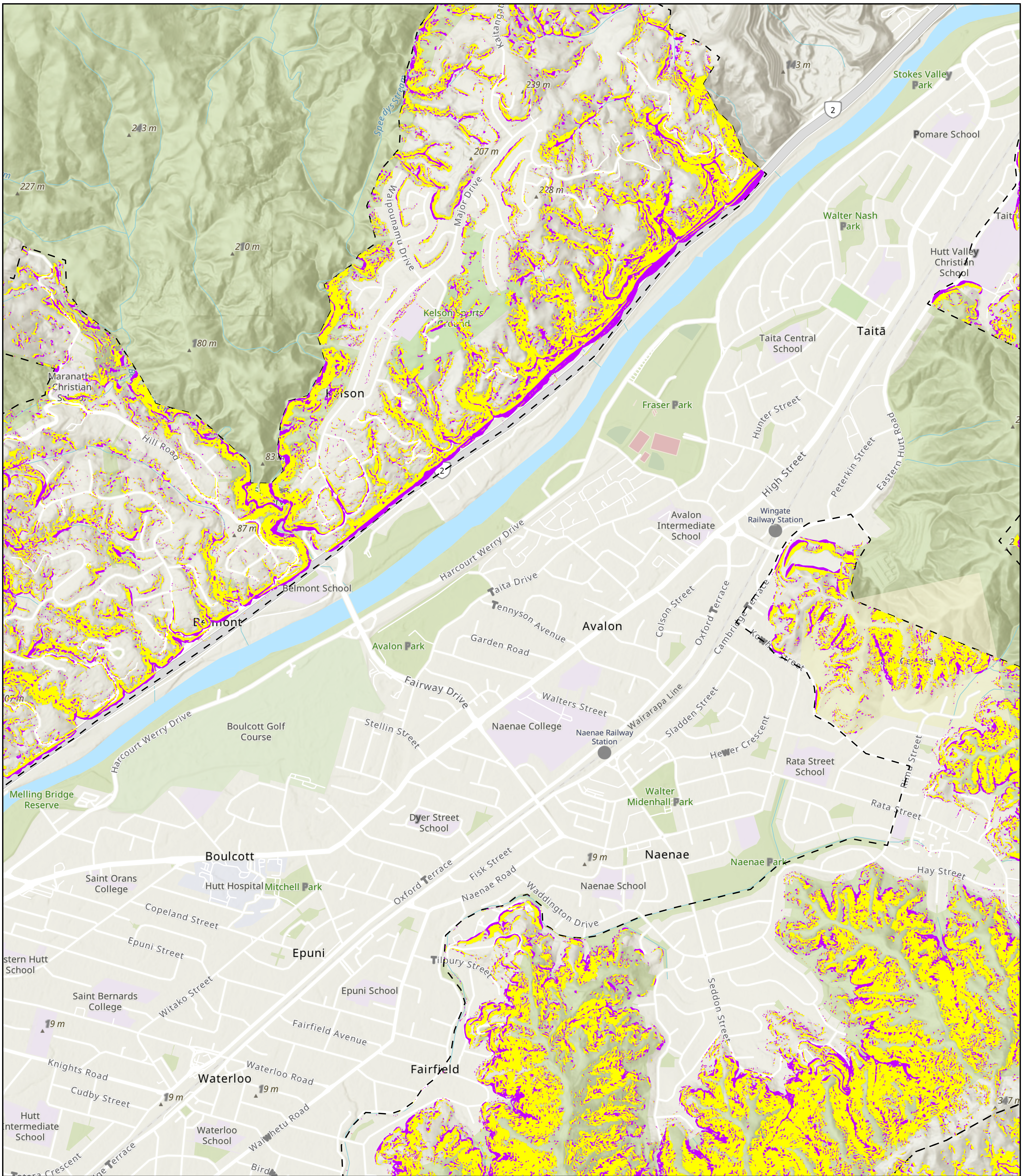
Date: 07/06/2024

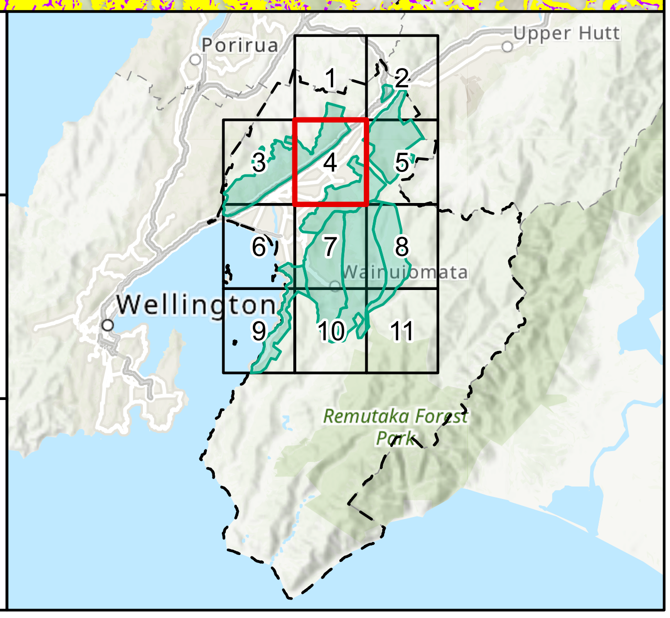
Project: 5-C4307.01

Legend:

- Failure Zones
- Runout Zones
- Focus Activity Areas







Landslide Susceptibility Zones for District Plan

Failure and Runout Zones

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Scale:

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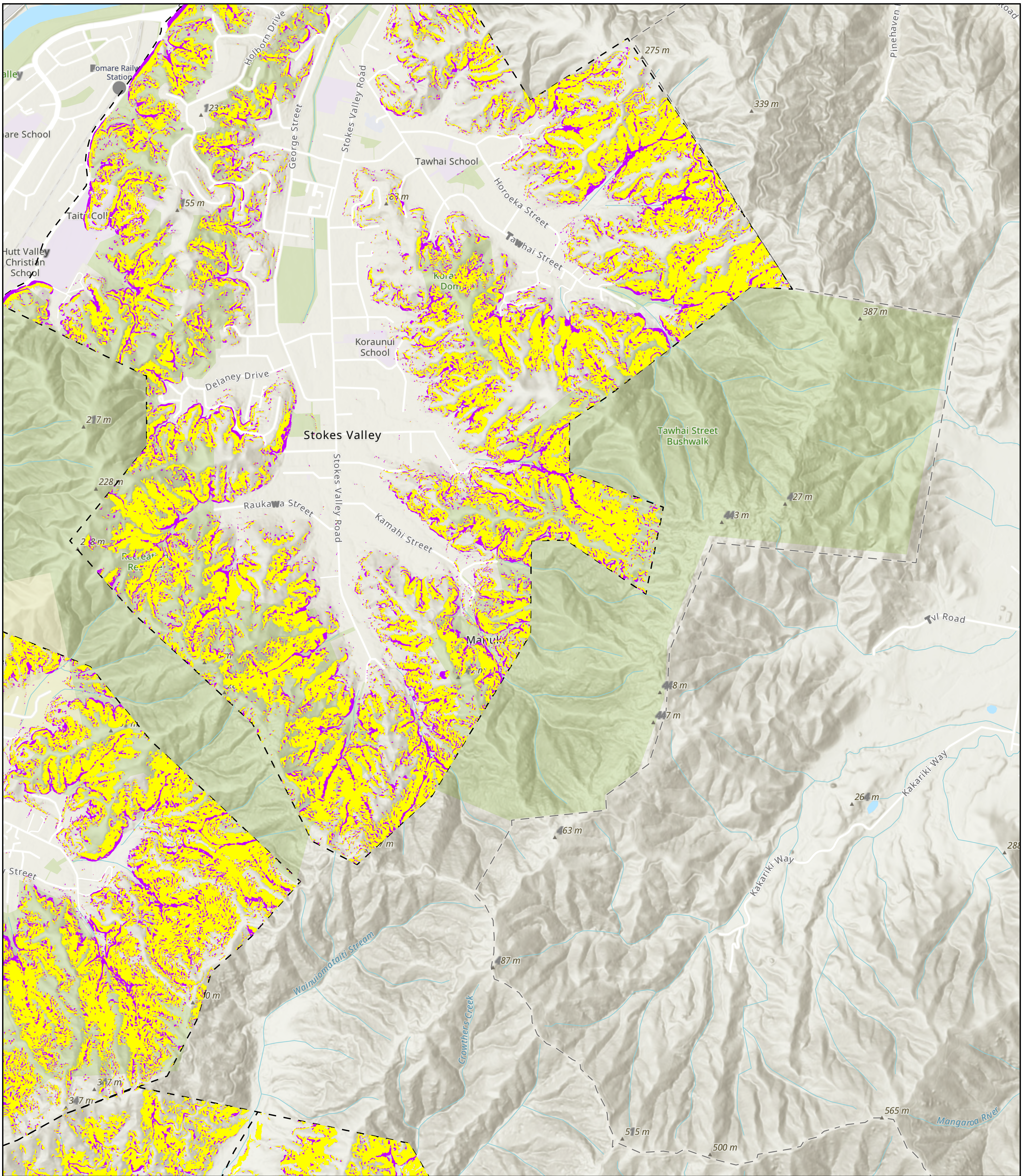

Landslide Susceptibility Zones for District Plan
Failure and Runout Zones

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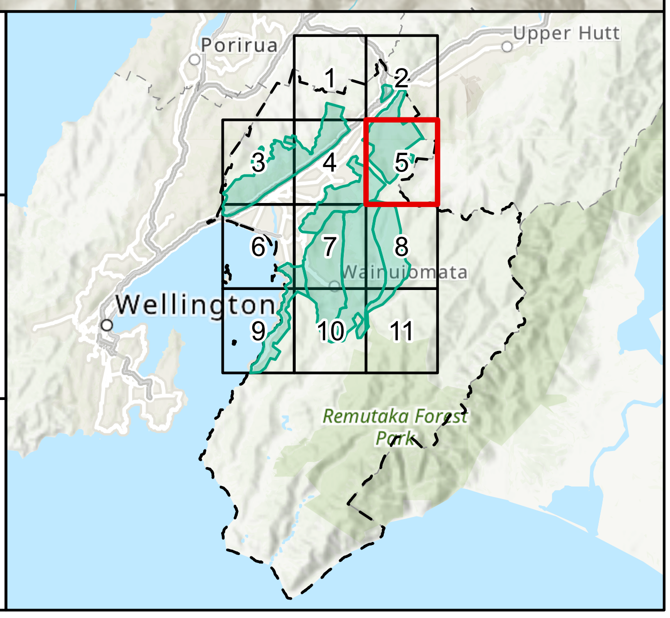

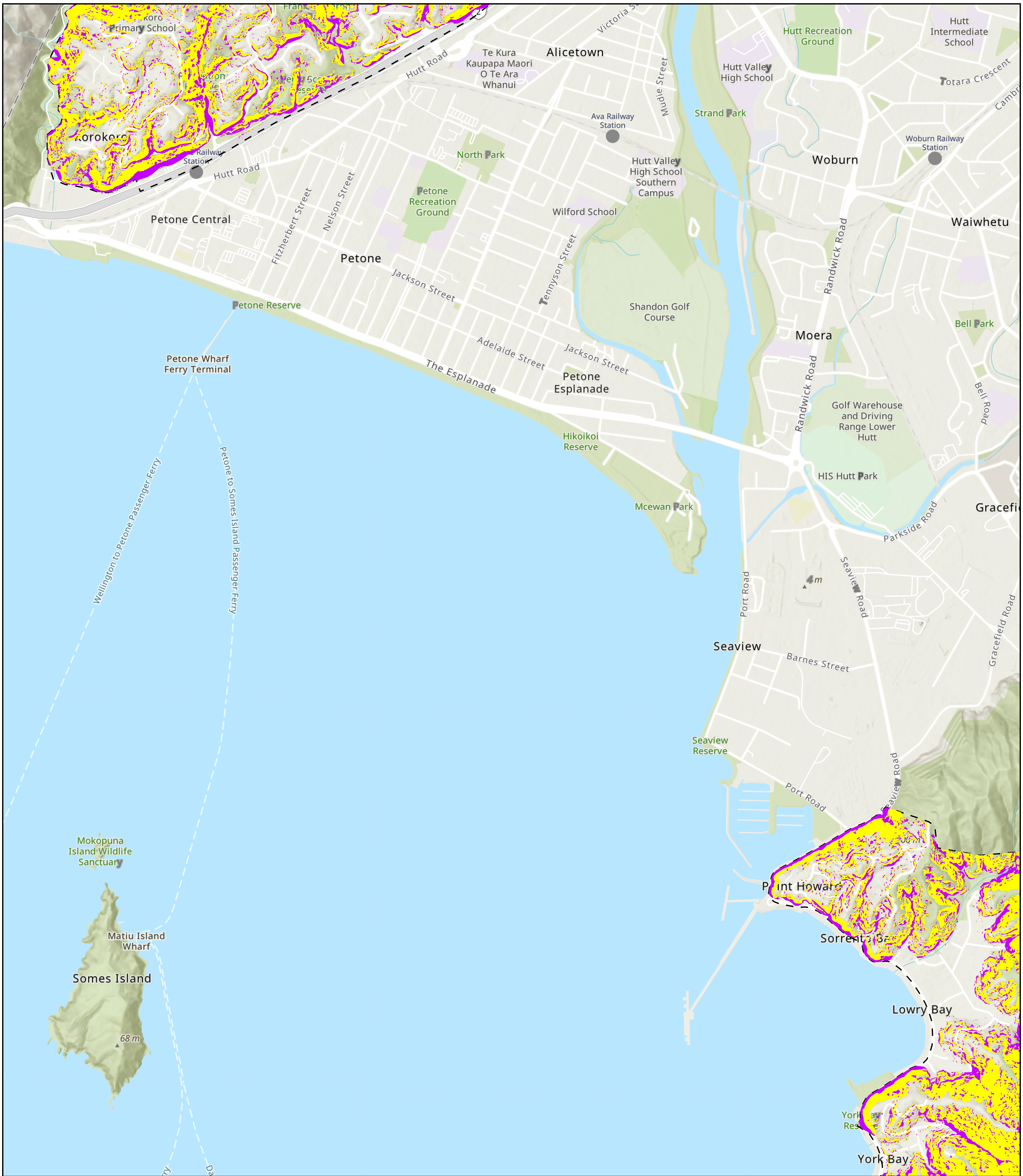

Landslide Susceptibility Zones for District Plan

Failure and Runout Zones

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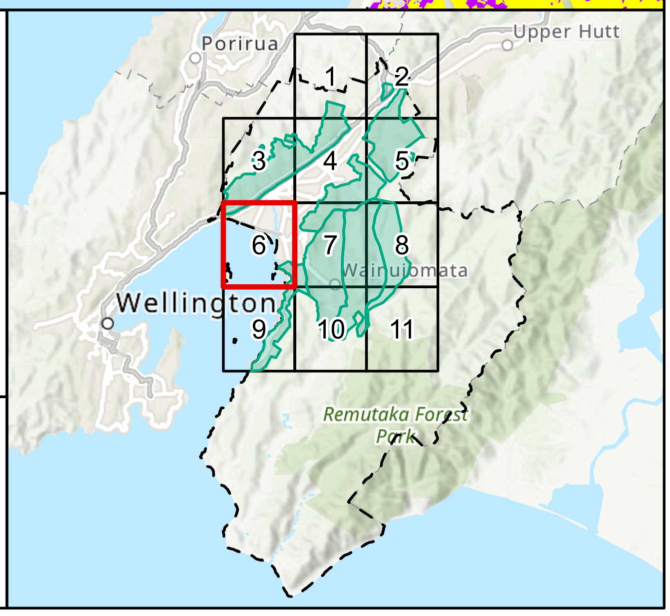

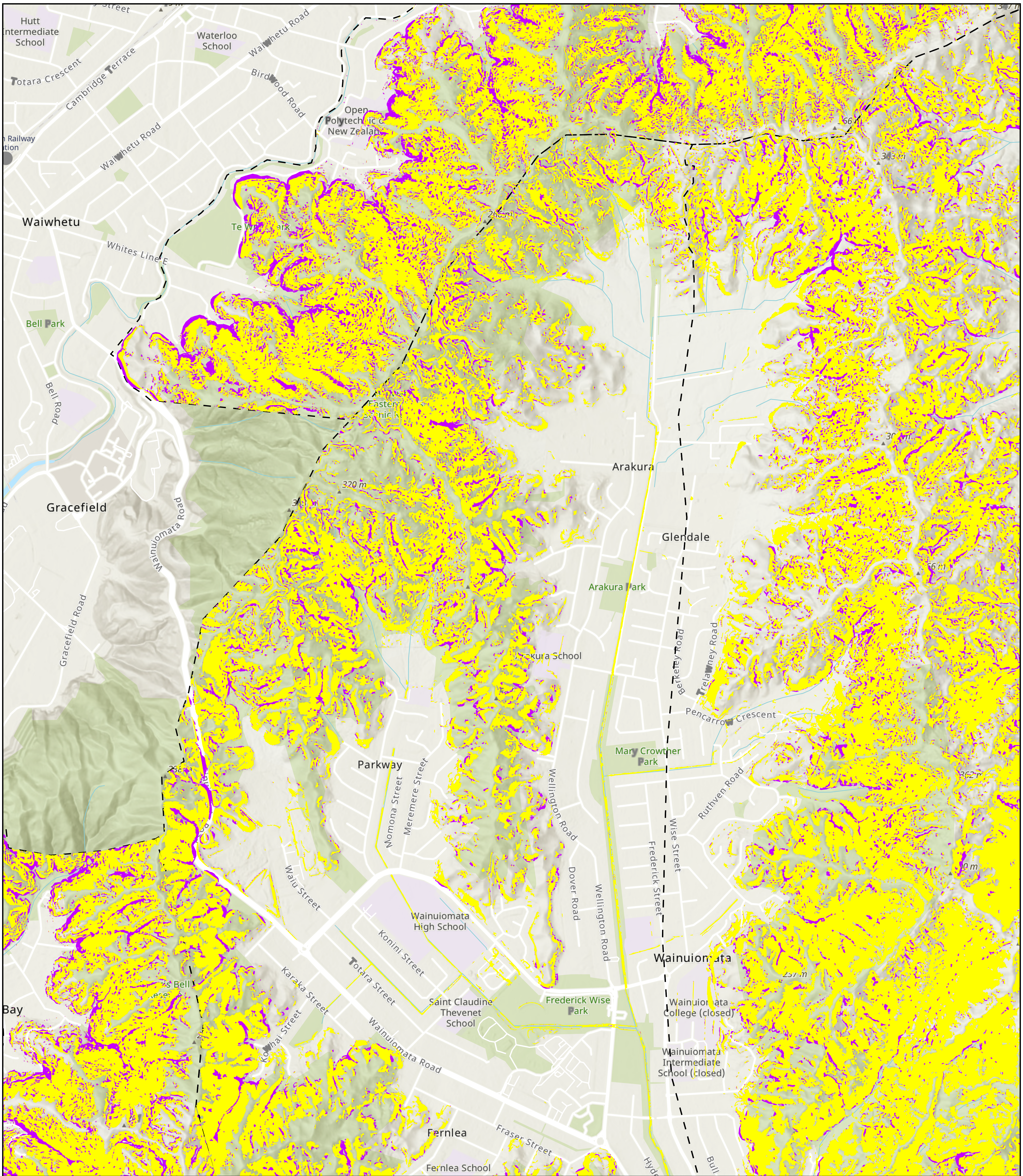

Landslide Susceptibility Zones for District Plan
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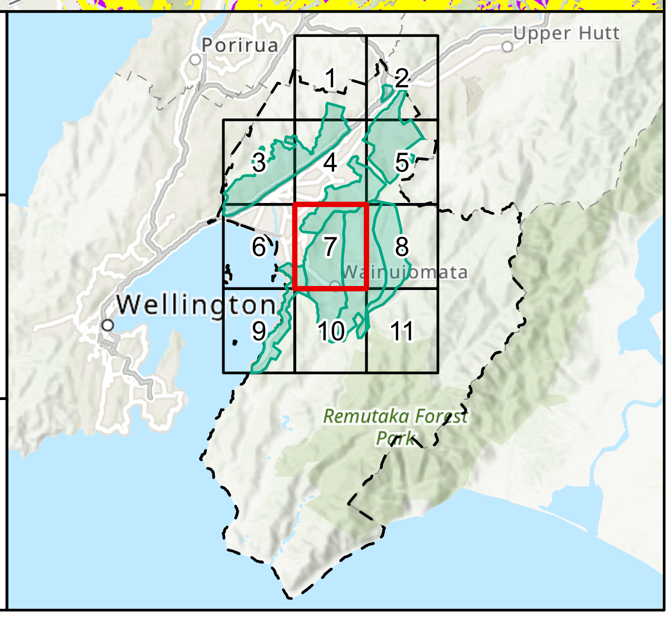

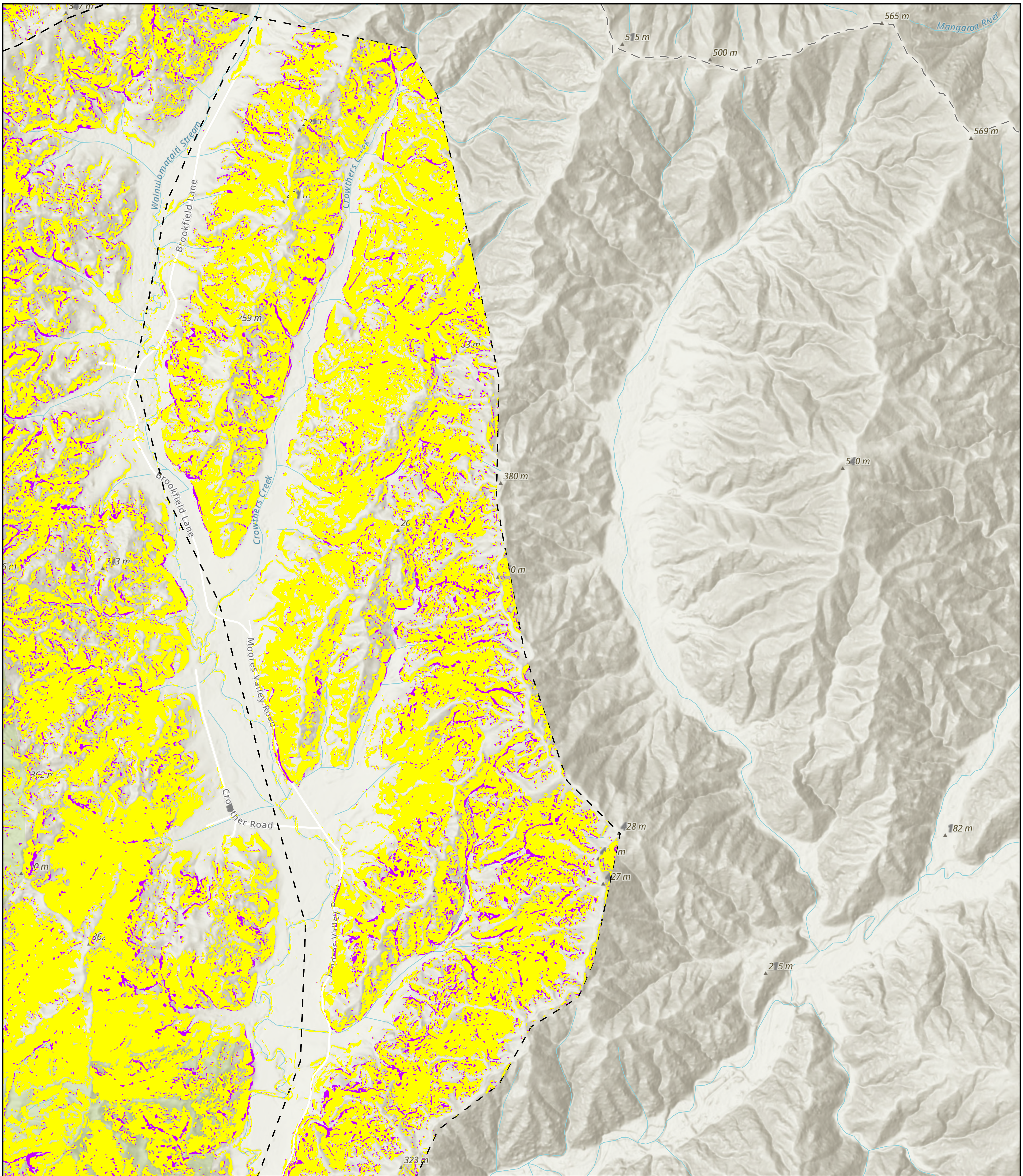

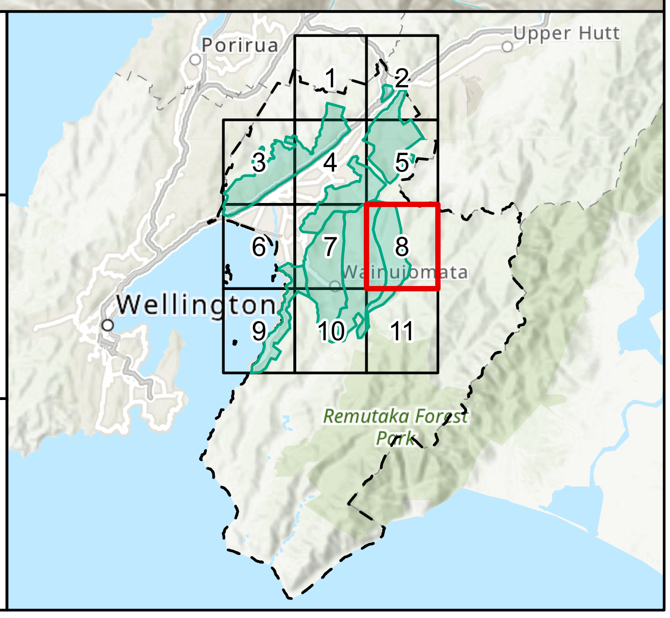

Landslide Susceptibility Zones for District Plan
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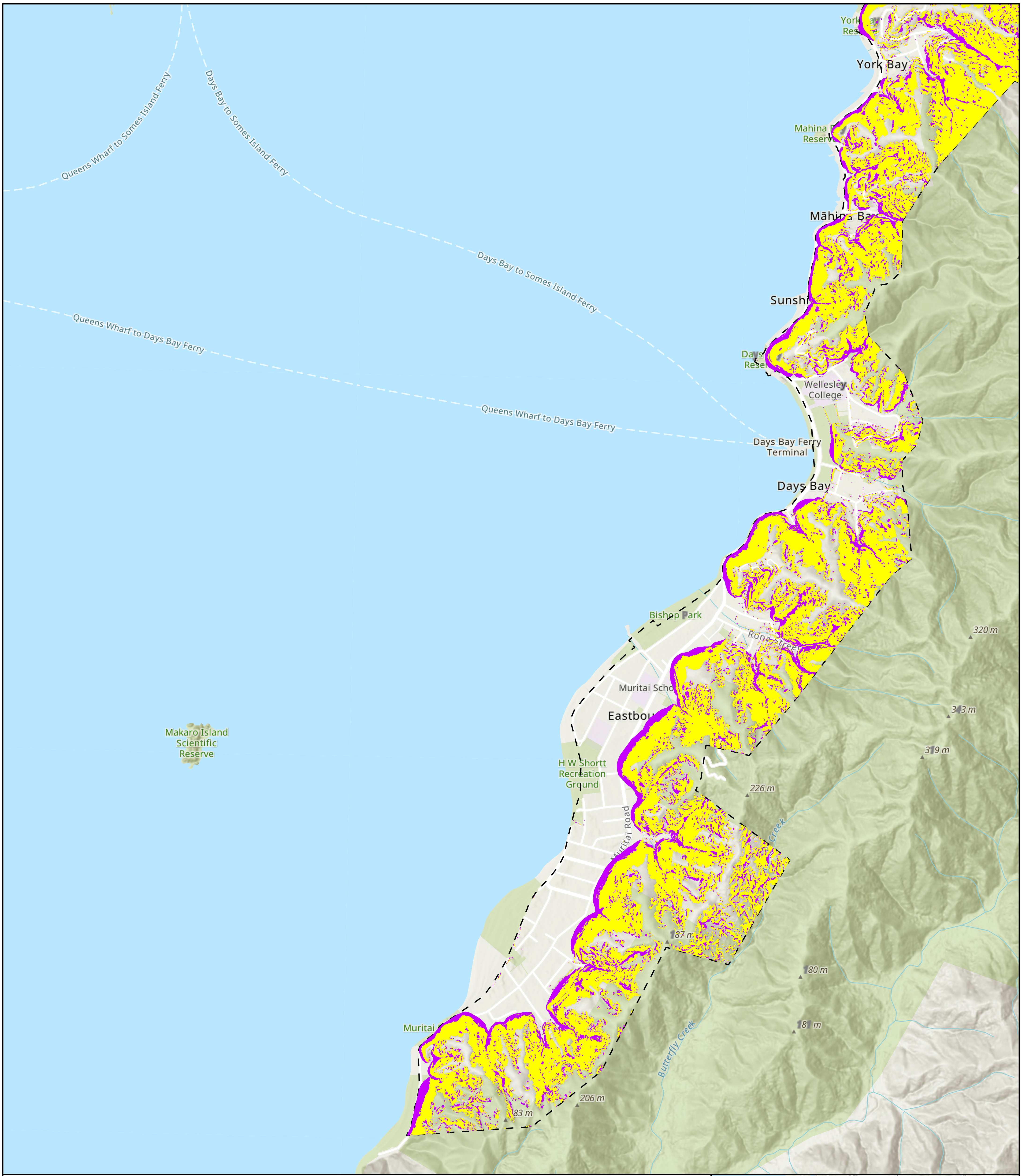

Landslide Susceptibility Zones for District Plan

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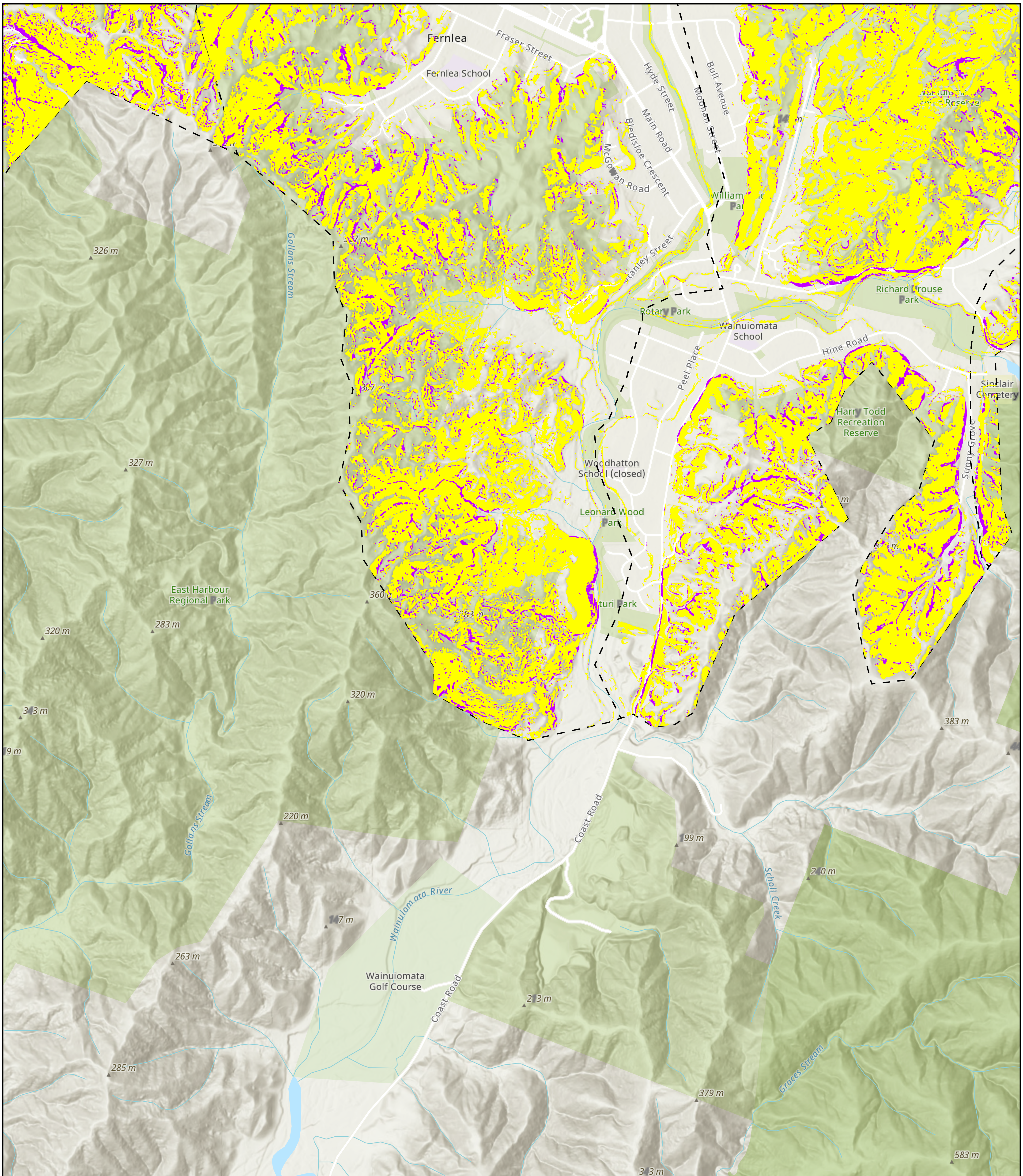

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Failure and Runout Zones

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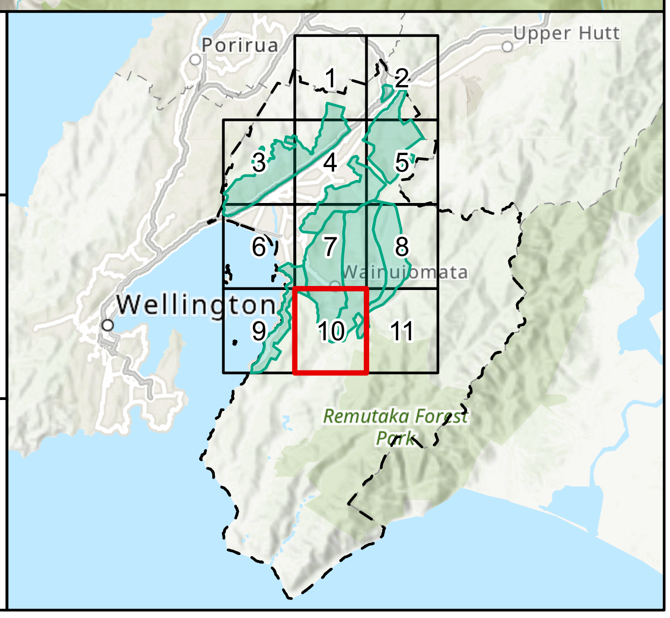

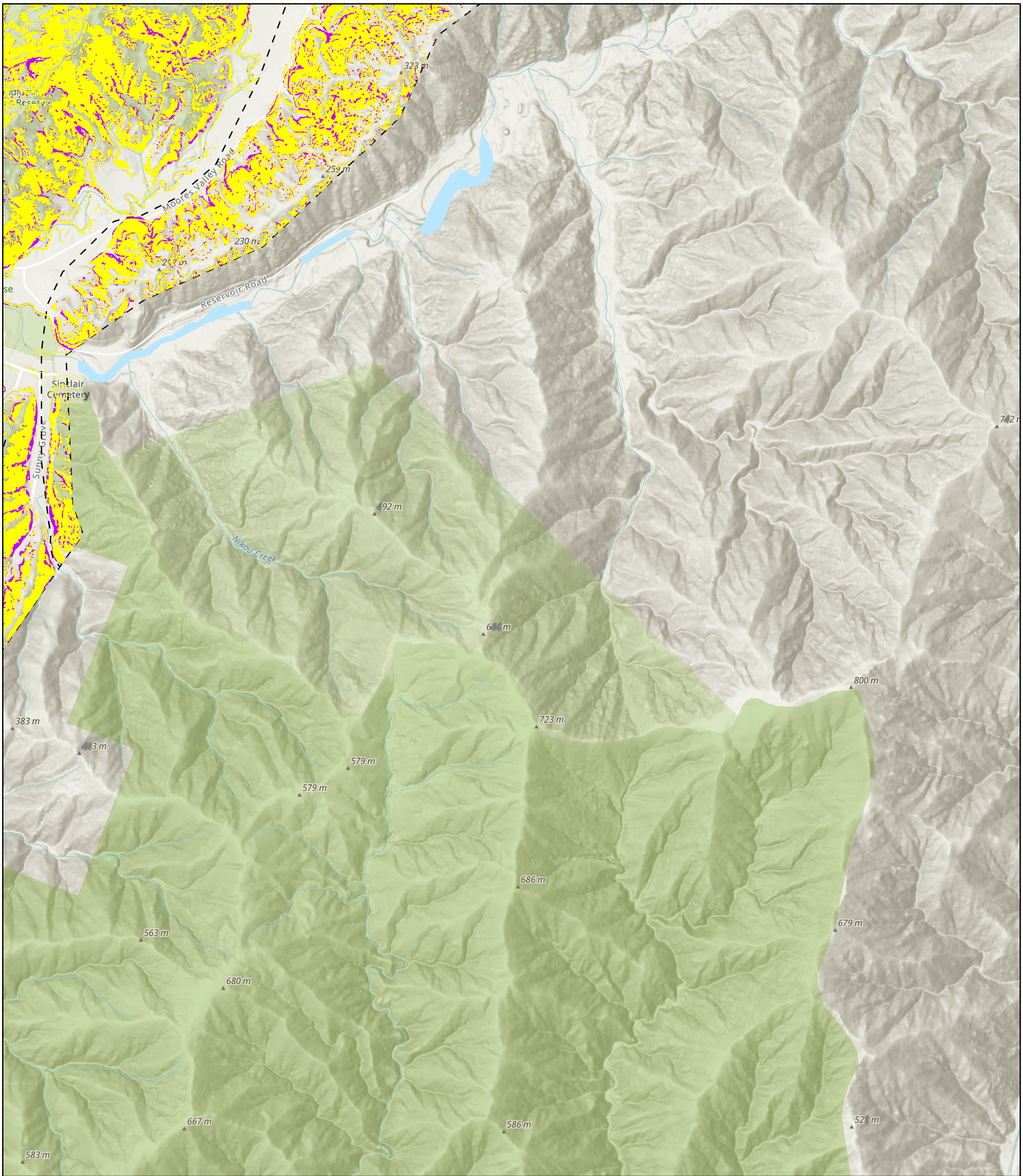

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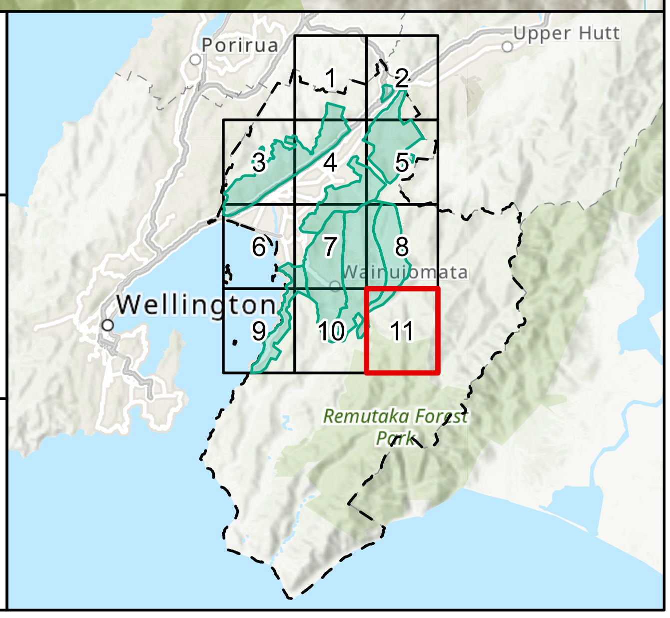

APPENDIX C

CHARACTERISTIC LANDSLIDES 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.	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
Hancox GT, Dellow GD, Massey C, Perrin, ND. 2006. Reconnaissance studies of landslides caused by the July-October 2006 rainstorms in southern North Island, New Zealand. GNS Science Report 2006/26. 37pp.
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)