# Memorandum

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| From | [redacted] |
| Office | Tauranga |
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| Subject | Tauranga Landslide Study – Mount/Papamoa Update |

## 1 Introduction

Following discussions between Tauranga City Council (TCC) and their Peer Reviewer ([redacted] ([redacted] ENGEO), WSP have reviewed the slope hazard methodology for the Mount Maunganui and Papamoa areas, including Hopukiore Mount Drury. This memo discusses the review, methodology and provides recommendations.

## 2 Methodology

We have undertaken the following:

- Reviewed background information on geology, geomorphology, ground conditions and slope failure typical in the Mount Maunganui and Papamoa areas, including Hopukiore Mount Drury, and environs similar, including:
  - A review of the landform and geomorphology of Hopukiore Mount Drury, identifying possible debris / colluvium around the base and previous slope failure features (i.e. headscarps).
  - A review of the geomorphology at Te Tumu, identifying typical landform and dune morphology and possible slope failure features.
- Geospatial analysis and slope modelling to outline a potential landslide hazard mapping method for Hopukiore Mt Drury and unmodified Papamoa slopes (Te Tumu).
  - Use of the visibility tool in ArcGIS Pro used to identify 2.75H:1V and 2.5H:1V runout zones in the Hopukiore Mount Drury and Papamoa area. These runout zones were identified from geomorphological analysis.
  - Slope modelling was undertaken in Slope/W using Mohr-Coulomb for four slopes in the study area (three in Papamoa and one at Hopukiore Mount Drury). Two cases were considered:
    - *Case 1: Normal conditions. Static. Target Factor of Safety (FoS) 1.5.*
    - *Case 2: Storm event. Elevated groundwater. Target FoS 1.2.*

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The seismic case was excluded, as this was also excluded in the original slope instability mapping for Tauranga City.

# 3 Results

## 3.1 Geomorphology and Unit Parameters

Hopukiore Mt Drury is part of the Mount Maunganui Group (2.35Ma) – and comprises biotite rhyolite lava (as is Motuotau and Motoriki islands) and genetically related to the Mauao lava dome (Briggs et al., 2005). Rock outcrops can be seen, particularly at road level (particularly on the SE and E) with boulders within soil matrix near the summit. The summit, north and west sides have ash, rock, soil and sand cover to unknown depths. Localised failures in this material may occur in isolated areas of the dome (as is seen at Mauao).

Sand dunes naturally form at the angle of repose, which generally prevents the creation of large, stable steep slopes over time. For instance, wave-cut dunes often fail shortly after being cut by water (e.g., ocean or river). However, a review of the landform at Te Tumu reveals that steep slopes > 4 m are present, particularly to the southeast near the Kaituna River. Ground investigations in this area show dense sands from approx. 6 m below ground level. These slopes are vegetated and not subject to erosion by water bodies.

A review of the Papamoa / Mount Maunganui urban landform indicates that many slopes in the built-up areas, as identified by LIDAR imagery, are due to retaining walls. These walls were constructed to create stable building platforms in sand rather than to address potential future slope instability in natural slopes > 4 m in height.

Units and unit parameters were derived from nearby geotechnical reports and investigations in the Papamoa area (Table 1). No information on ground conditions is available from the NZ Geotechnical Database (NZGD) or internal WSP records for Hopukiore Mount Drury, therefore parameters were estimated based on conservative assumptions of the soil/rock profile and observations of the rock materials exposed in outcrops around the base of Hopukiore Mount Drury considering fractures and rock defects.

*Table 1: Unit parameters used in the slope modelling.*

| Area | Unit Name | Unit Weight ($kN/m^3$) | Effective Cohesion (kPa) | Effective Friction Angle (°) |
|---|---|---|---|---|
| Papamoa | Loose to medium dense sands [Holocene-aged dune and beach deposits] | 18 | 1 | 32 |
| | Medium to dense sands [Holocene-aged beach deposits] | 18 | 1 | 34 |
| Drury | Silt [Topsoil] | 17 | 5 | 28 |
| | Rock [Neogene Igneous rock] | 19 | 30 | 33 |

## 3.2 Slope Runout

The slope runout distance was established from an analysis of the geomorphology and landform (Refer to Section 3.1). Figure 1 and Figure 2 display slope runout results for Hopukiore

Mount Drury and Papamoa, respectively, for 2.75H:1V and 2.5H:1V runout zones mapped in ArcGIS Pro and compared to existing 4H:1V runout zones.

The results shown in Figure 1 indicate that for Hopukiore Mount Drury a runout distance equating to 2.5H:1V is appropriate for landslides initiated from the soil, ash and weathered rock debris in the upper part of the landform. This runout distance would also encompass potential rockfall initiated from the lower part of the landform, as we note that colluvium and rock boulders are visible around the base of Hopukiore Mount Drury and are within the 2.5H:1V runout zone.


*Figure 1: Mt Drury landslide zones.*

A range of runout distances were mapped and based on the geomorphology and landform, Figure 2 compares the 2.75H:1V and 2.5H:1V runout zones for Papamoa with the 4H:1V runout zones. This map also shows the extent of the slopes with a Factor of Safety (FOS) of 1.5, assessed using Slope/W. This comparison assesses the impact of different runout zone mappings in the sand dune landform. In areas D and C (Figure 2), the runout zones exhibit minimal differences.


*Figure 2: Papamoa landslide zones.*

Considering the friction angle and failure characteristics of sand, a runout length of 2.5H:1V is more suitable than the longer runout lengths used for saturated ash soils.

## 3.3 Slope Regression

### *3.3.1 Hopukiore Mount Drury*

Slope modelling for Hopukiore Mount Drury was conducted in Slope/W using the Mohr-Coulomb method. The aim was to investigate failure and regression zones.

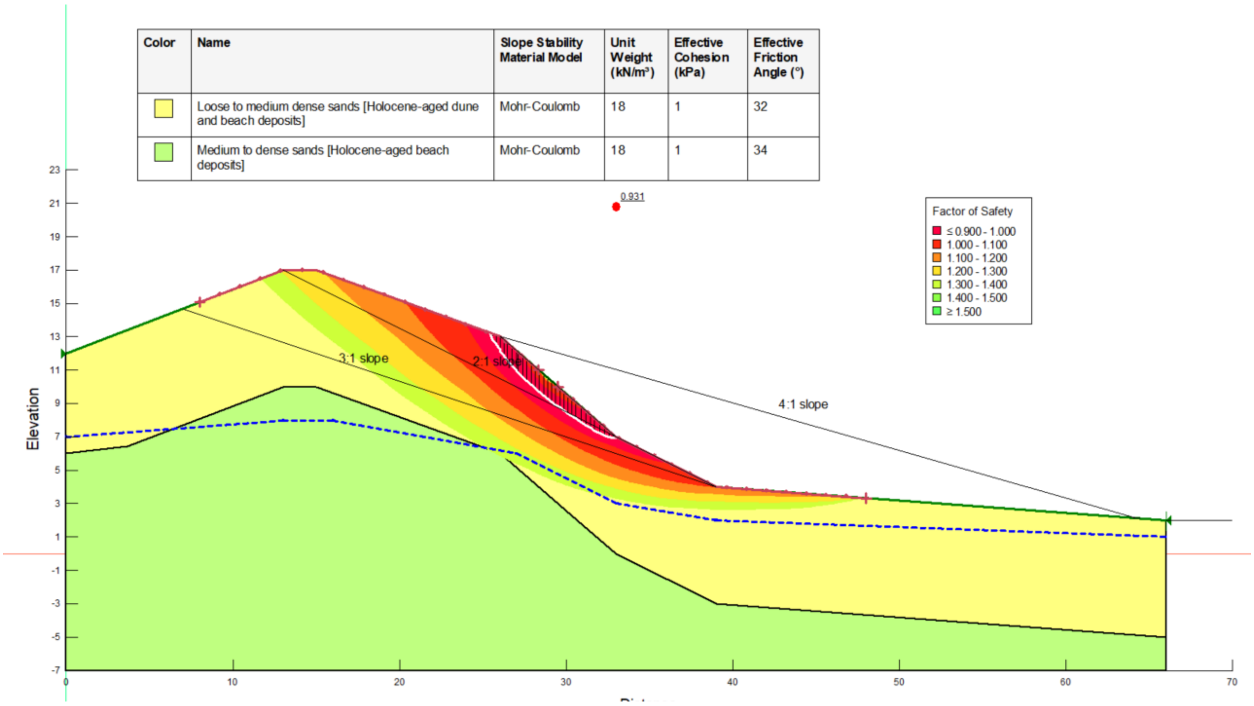
Inherent uncertainties in the ground profile due to a lack of site-specific information on material properties and groundwater conditions limit the usefulness of the slope modelling for analysing the failure zone, and a deterministic approach to identify regression cannot be made based only on the models.

### *3.3.1 Papamoa*

Slope modelling was undertaken in Slope/W using the Mohr-Coulomb method for three natural sand dune slopes in the Papamoa / Te Tumu area considering 1) normal static conditions and 2) a storm event using an elevated groundwater table (Figures 3 to 8). A parametric analysis was also performed to assess the sensitivity of this analysis to the soil parameters assumed.

Our knowledge of slope failures in sand dune materials is that they are typically dominated by translational to semi-rotational slump-type failure, with an approximate long-term stable angle of 2H:1V. In all sections, the results indicate that the critical failure surface aligns with typical sand failure, occurring at the steepest part of the dune.

Under static conditions, the target FoS (1.5 for static and 1.2 for elevated groundwater as used in the IDC) lies between the failure and regression lines, indicating that the 3H:1V slope is overestimating regression, and a 2.5H:1V slope may be more suitable.



| Color | Name | Slope Stability Material Model | Unit Weight (kN/m³) | Effective Cohesion (kPa) | Effective Friction Angle (°) |
|---|---|---|---|---|---|
| | Loose to medium dense sands [Holocene-aged dune and beach deposits] | Mohr-Coulomb | 18 | 1 | 32 |
| | Medium to dense sands [Holocene-aged beach deposits] | Mohr-Coulomb | 18 | 1 | 34 |



*Figure 3: Section B-B' Case 1: Normal Conditions. Static.*

| Color | Name | Slope Stability Material Model | Unit Weight (kN/m³) | Effective Cohesion (kPa) | Effective Friction Angle (°) | Piezometric Surface | Include Ru in PWP |
|---|---|---|---|---|---|---|---|
| | Loose to medium dense sands [Holocene-aged dune and beach deposits] | Mohr-Coulomb | 18 | 1 | 32 | 1 | No |
| | Medium to dense sands [Holocene-aged beach deposits] | Mohr-Coulomb | 18 | 1 | 34 | 1 | No |

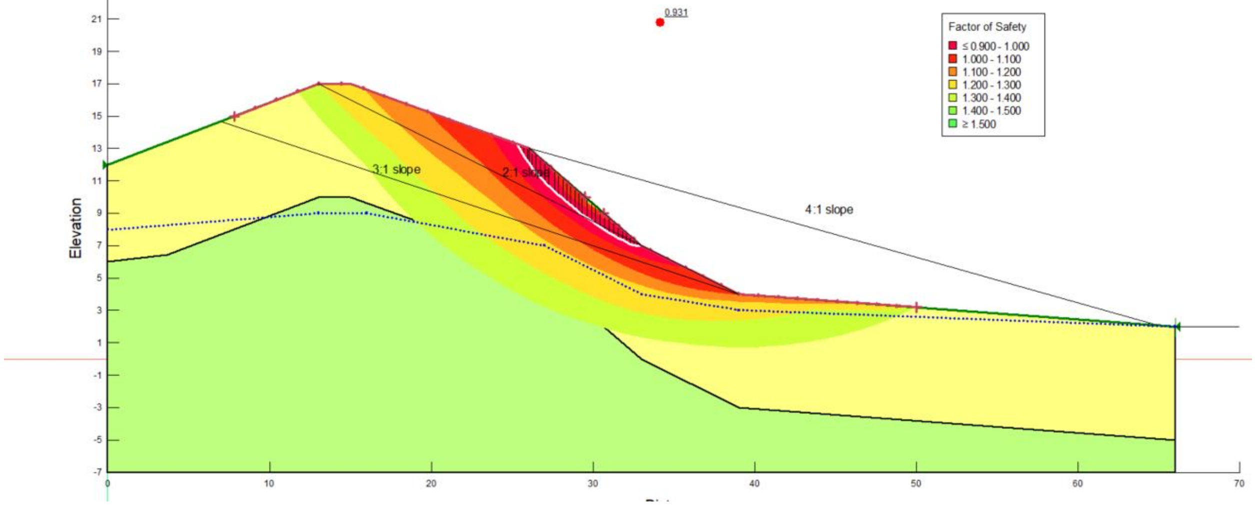



*Figure 4: Section B-B' Case 2: Storm event. Elevated groundwater.*

| Color | Name | Slope Stability Material Model | Unit Weight (kN/m³) | Effective Cohesion (kPa) | Effective Friction Angle (°) |
|---|---|---|---|---|---|
| | Loose to medium dense sands [Holocene-aged dune and beach deposits] | Mohr-Coulomb | 18 | 1 | 32 |
| | Medium to dense sands [Holocene-aged beach deposits] | Mohr-Coulomb | 18 | 1 | 34 |

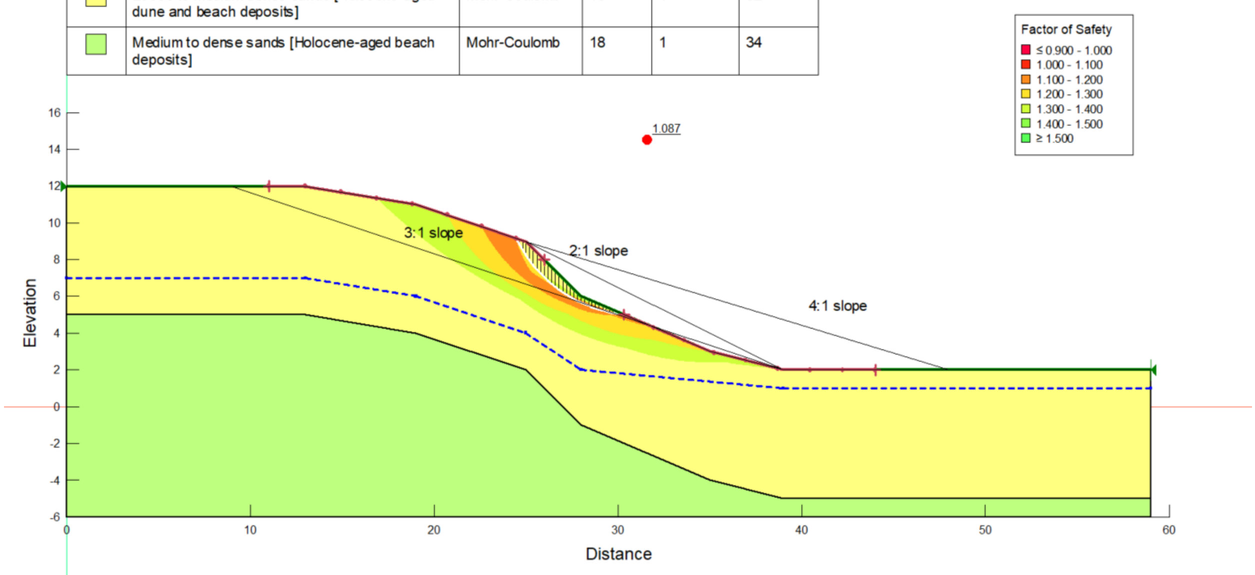
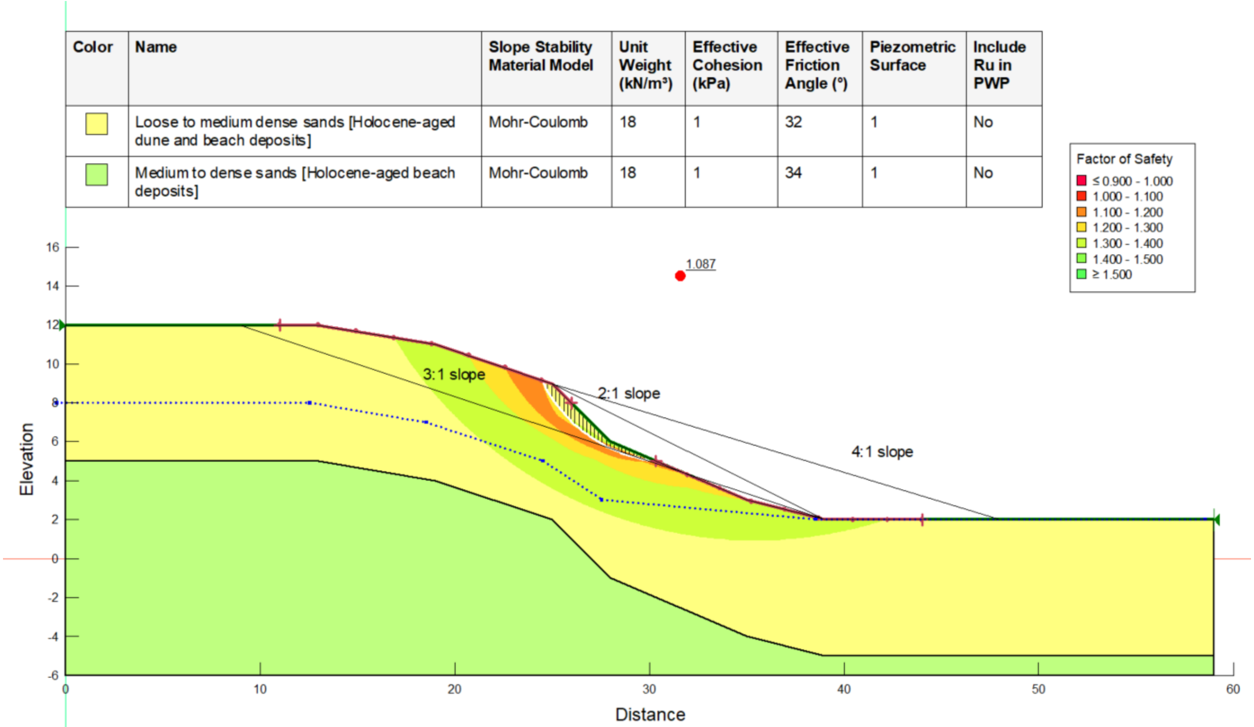


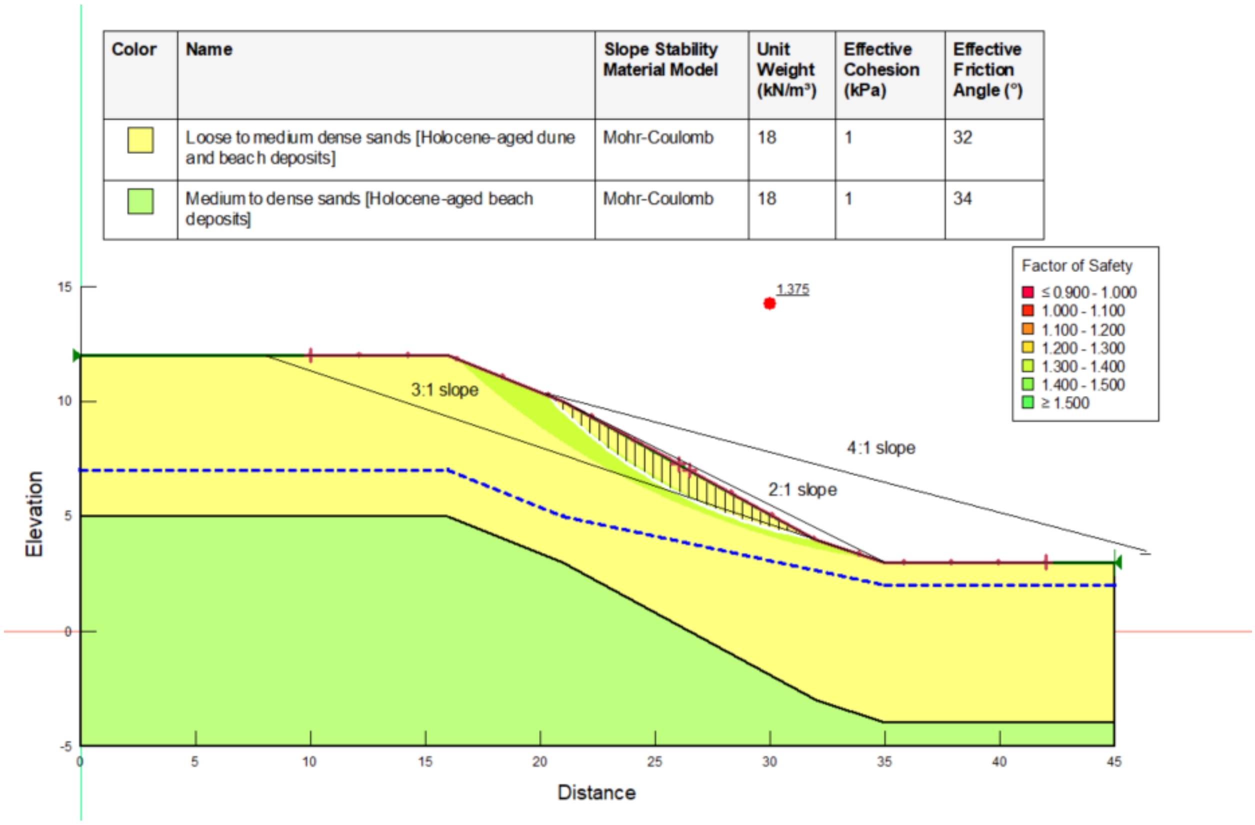

*Figure 5: Section C-C' Case 1: Normal Conditions. Static.*



| Color | Name | Slope Stability Material Model | Unit Weight (kN/m³) | Effective Cohesion (kPa) | Effective Friction Angle (°) | Piezometric Surface | Include Ru in PWP |
|---|---|---|---|---|---|---|---|
| | Loose to medium dense sands [Holocene-aged dune and beach deposits] | Mohr-Coulomb | 18 | 1 | 32 | 1 | No |
| | Medium to dense sands [Holocene-aged beach deposits] | Mohr-Coulomb | 18 | 1 | 34 | 1 | No |



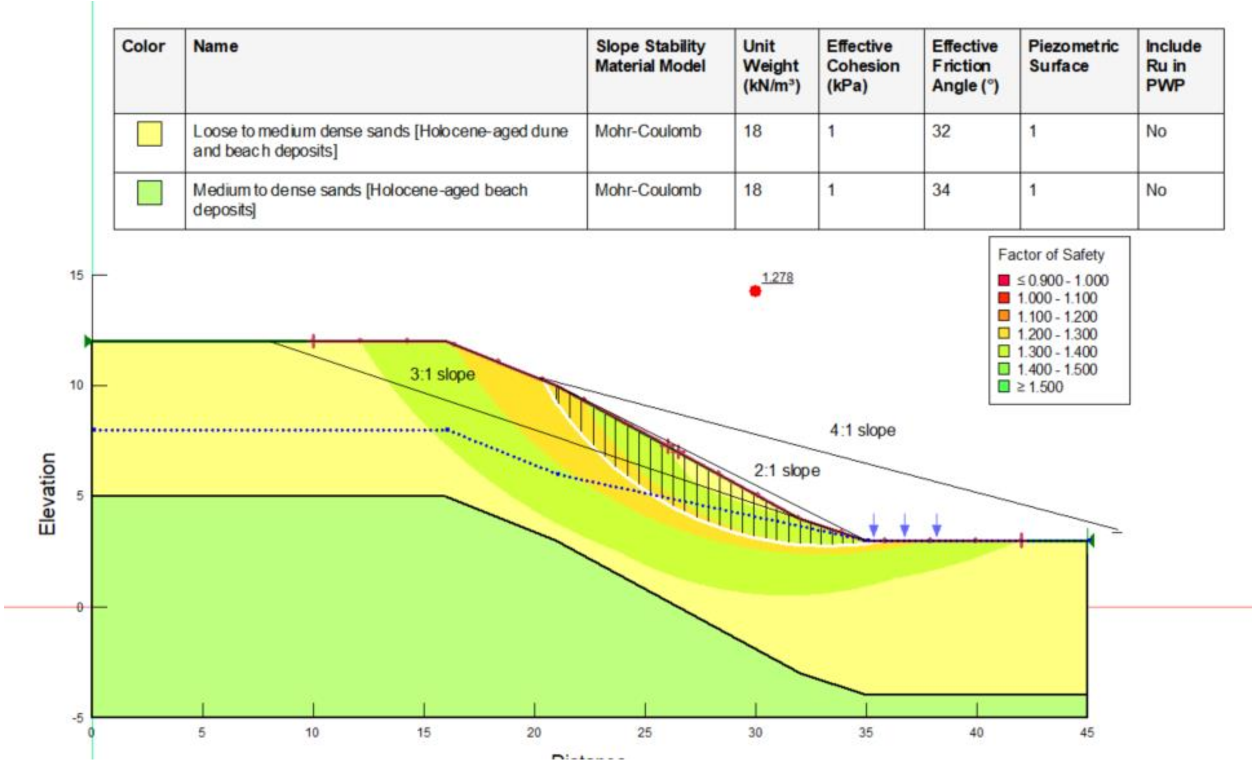
*Figure 6: Section C-C' Case 2: Storm event. Elevated groundwater.*



| Color | Name | Slope Stability Material Model | Unit Weight (kN/m³) | Effective Cohesion (kPa) | Effective Friction Angle (°) |
|---|---|---|---|---|---|
| | Loose to medium dense sands [Holocene-aged dune and beach deposits] | Mohr-Coulomb | 18 | 1 | 32 |
| | Medium to dense sands [Holocene-aged beach deposits] | Mohr-Coulomb | 18 | 1 | 34 |



*Figure 7: Section D-D' Case 1: Normal Conditions. Static.*



| Color | Name | Slope Stability Material Model | Unit Weight (kN/m³) | Effective Cohesion (kPa) | Effective Friction Angle (°) | Piezometric Surface | Include Ru in PWP |
|---|---|---|---|---|---|---|---|
| | Loose to medium dense sands [Holocene-aged dune and beach deposits] | Mohr-Coulomb | 18 | 1 | 32 | 1 | No |
| | Medium to dense sands [Holocene-aged beach deposits] | Mohr-Coulomb | 18 | 1 | 34 | 1 | No |



*Figure 8: Section D-D' Case 2: Storm event. Elevated groundwater.*

# 4 Conclusions and Recommendations

## 4.1 Conclusions

### *4.1.1 Hopukiore Mount Drury*

The mapped failure zone is believed to represent typical landslide initiation points, generally on moderately steep to steep slopes, including rock slopes. Geomorphological evidence and knowledge of slope failures and runout in rock and soil slopes support revising the slope runout to 2.5H:1V (refer to Figure 1).

There is too much uncertainty to identify appropriate failure mechanisms as insufficient information available to inform the modelling, and therefore the regression zone cannot be clearly defined. Conducting a site-specific study at this location is beyond the scope of this city-wide landslide study and the objective of mapping at a 1:5000 scale. However, we believe the regression zone could conservatively represent an area upslope of a failure zone that if landslides are not identified and/or remediated, the land within the regression zone may become more vulnerable to landslides over time.

### *4.1.2 Mount / Papamoa*

The FoS of 1.5, as modelled in Slope/W for Te Tumu, encompasses the previously mapped failure zone shown in Figure 2. Based on our understanding of failure in sand dunes, the 4H:1V runout model overestimates the actual slope runout, which is likely to be less, around 2.5H:1V.

The regression zone is challenging to determine using Slope/W, but a regression of approximately 2.5H:1V seems appropriate and is consistent with our observations of the long-term behaviour of slopes in dune sand materials. This zone would represent an area upslope from instability that might develop if landslides are not identified and/or remediated.

## 4.2 Recommendations

We recommend removing slope hazard zones for slope features < 4 m in urbanised areas within Mount Maunganui and Papamoa, and updating the regression and runout zones to 2.5H:1V and 2.5H:1V, respectively as illustrated in Figure 9.

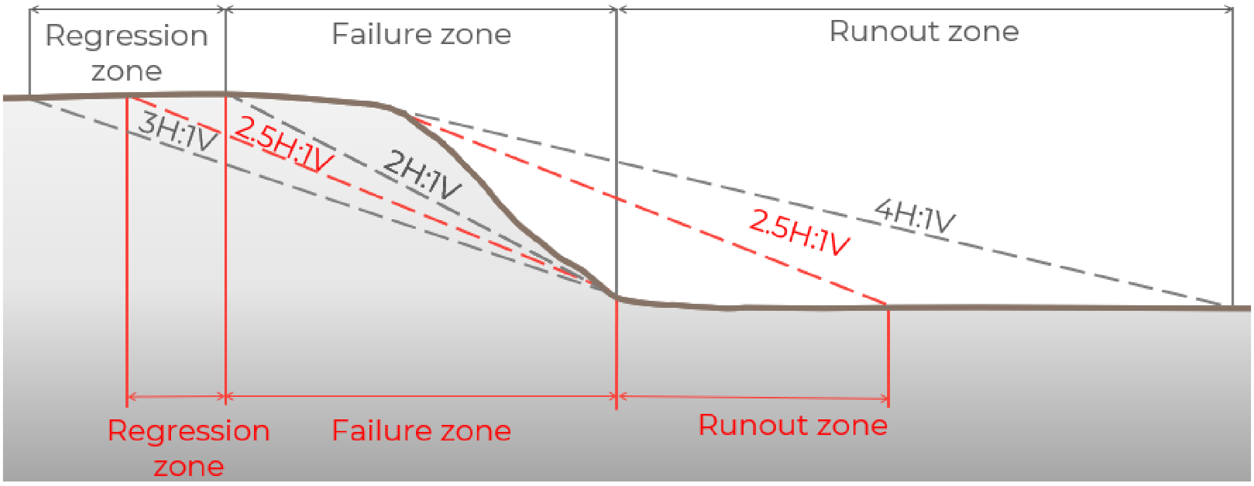



*Figure 9: Proposed runout and regression zones for Papamoa and Mount Maunganui shown in red, current zones are shown in grey. Note the failure zone remains the same.*