# The Use of A Geotechnical Constraint Map to Inform Subdivision Development: A Case Study

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**ABSTRACT**

One of the biggest challenges faced by geo-professionals is how to convey complex information to non-technical end users. One method of conveying information in a straightforward manner is the use of geotechnical constraints mapping. A case study is presented for a site in the Maymorn Region of Wellington, New Zealand, where several geotechnical limitations for future subdivision were identified. The geomorphology of the site comprises level ground across the western side of the site, incised by a stream channel in the north; with hills present across the eastern side of the site. The flat area of the site has experienced historical filling of the stream channel and settling ponds associated with farming. The hill areas of the site have been extensively modified by forestry works. The geomorphology and past site works suggest a large number of geological hazards may affect future land use. These comprise liquefaction, lateral spreading and static settlements across the flat areas of the site; with landsliding (both shallow and deep seated), debris flows and rockfall across the sloping areas of the site. For each area of the site, we considered the risk posed by each hazard to the development and assigned it a rating class, from 1 (lowest) through 5 (highest). This was presented in a geotechnical constraints map with coloured zones reflecting each of the rating classes. The end result provided an easy and concise means of conveying extensive technical information to the end user who was readily able to apply it to their decision-making.

*Keywords:* geohazard, risk, constraints map, case study, Maymorn, Wellington

## 1 INTRODUCTION

The process of clearly and concisely convey complex geotechnical information to non-technical end users is a common problem faced by geo-professionals. While various different approaches exist, the use of constraints mapping presents an effective method in which to summarise this information while conveying implications for a specific project, in this case subdivision development.

This paper illustrates how numerous geological hazards can be summarised onto a single constraints map, based on a case study site located in the Maymorn region of Wellington, New Zealand. The intended use of the constraints map was to inform land development works, such that areas with low risk could be intensively developed while areas of higher risk could be avoided as much as practicable.

## 2 CASE STUDY

### 2.1 Site and Project Description

A geotechnical hazard assessment was required to inform development of an approximately 200 lot subdivision. The 74 ha site comprised relatively level ground across the western side, and sloping ground across the eastern side (Figure 1).

The flat area of the site is grass covered and used for cattle grazing. It is cut by a series of drainage channels which range from a steep sided natural meandering stream in the north-western portion of the site, to modified linear drainage features which flow into the natural stream channel and smaller drainage channels diverting water from the hills. The sloping area is currently vegetated, predominantly with pine forest. Generally, the ridgeline has a wide and relatively level crest. The adjacent slope angles typically range up to 35°, with isolated gullies where slope angles reach approximately 50°. Evidence of local areas of instability were observed through recent failures and bowing of tree trunks.

The Geological Q-map (Begg and Johnston, 2000) indicates that the flat areas are underlain by alluvial gravel, described as late Pleistocene poorly to moderately sorted gravel with minor sand or silt. The hills are mapped as being underlain by grey sandstone-mudstone sequences and poorly bedded sandstone of the Rakaia Terrane (commonly termed Greywacke). The site is located in an area of active seismicity, with the Wellington Fault to the northwest (2 km) and the Wairarapa Fault to the southeast (11 km).

*Figure 1: Site Photographs: Left – Typical flat geomorphology of flat area with meandering stream channel; Right – View of sloping areas of site.*

The site has been extensively modified over time. Prior to 2008 the flat area of the site was used as a pig farm, and a series of effluent ponds were present near the base of the hills. At that time, the meandering stream channel also extended further to the south. Both the ponds and stream channel were infilled as the piggery was decommissioned. The hill areas of the site have experienced modification, with the formation of forestry access tracks and successive rounds of logging and replanting altering the original terrain.

### 2.2 Ground Model

Critical to the assessment of site geohazards is the development of a detailed ground model. Across the hill area of the site, geomorphological mapping and logging of exposures in road cuts was undertaken. Across the flat areas of the site, where the geomorphology provides fewer clues to the nature of the ground conditions, a series of subsurface investigations were undertaken. The investigations comprised ten sonic machine boreholes to 19.95 m depth, and seven Cone Penetration Tests (CPT) to a maximum of 10.49 m depth.

Groundwater conditions varied across the site. Small streams were observed in the gullies across the hills, which may be seasonal in nature. Standing water was observed at the ground surface immediately adjacent to the base of the hills, with the depth to groundwater increasing to 3 m to 4 m below ground level around the stream channel in the northwest.

From the mapping and subsurface investigations, the site can be divided into several distinct areas. Across the hills, varying geological conditions were identified:

- Rock (Greywacke Sandstone), and shallow rock (areas with less than 3 m of soil cover).
- Colluvium (greater than 3 m in thickness).
- Alluvium (greater than 3 m in thickness).
- Landslide debris (both recent and historical).
- Fill, inferred to be associated with formation of forestry tracks.

Across the flat area, four geologically distinct areas were identified:

- Shallow dense gravels, located across the north-western side of the site.
- Fill associated with previous stream channel, extending up to 6.5 m thick.
- Fill associated with historical effluent ponds, extending up to 3 m thick.
- Interbedded silts and gravels of varying density across the remaining flat areas.

These geological conditions formed the basis for the hazard assessment described in the following section and are illustrated in Figure 2.

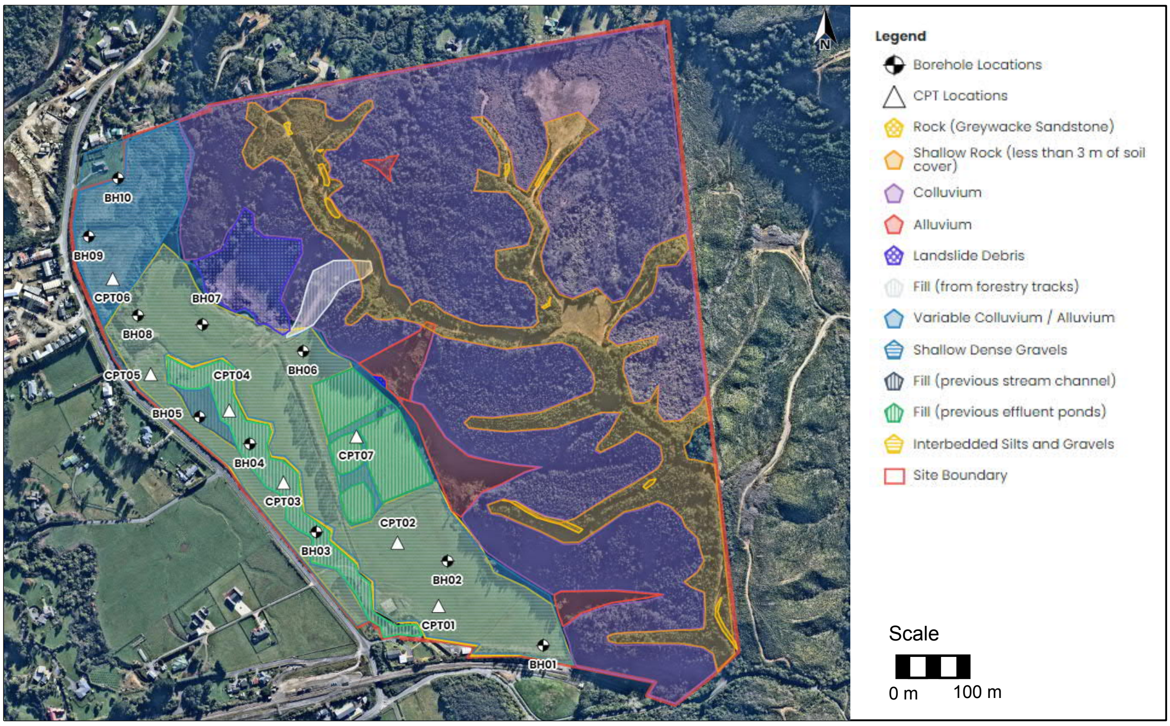


*Figure 2: Site Specific Interpretive Geological Mapping, with Subsurface Investigation Locations (street names not provided due to confidentiality)*

## 3 HAZARD ASSESSMENT

Natural hazards were assessed against Section 106 of the Resource Management Act to inform subdivision suitability, as outlined below. This assessment excludes hazards associated with flooding.

### 3.1 Flat Area Hazards

#### 3.1.1 Liquefaction

Liquefaction analysis was undertaken utilising the CPT data obtained for the flat areas of the site, following the methodology outlined within the Earthquake Geotechnical Engineering Practice Module 3 (2021), and groundwater from the surface as a conservative approach to reflect site observations. The analysis indicated very low levels of liquefaction induced vertical settlement under Serviceability Limit State (SLS) ground shaking conditions, with settlements due to thin lenses of potentially liquefiable material interspersed throughout the investigated soil profile. Under Ultimate Limit State (ULS) ground shaking conditions, higher settlements of up to 80 mm are indicated by the analysis, with individual layers of liquefiable material up to 2 m thick.

#### 3.1.2 Lateral Spreading

Lateral spreading occurs when there are continuous and uniform liquefiable layers that are able to move towards a ‘free face’. No lateral spreading was anticipated under SLS ground shaking conditions due to the lack of liquefiable layers of sufficient thickness in which to induce movement. While more of the ground profile is potentially liquefiable under ULS ground shaking conditions, the ground conditions are highly variable with no obvious evidence of a continuous and uniform liquefiable layer in which to trigger spreading. Accordingly, the potential for lateral stretch is considered to be low (stream bank regression is considered separately below). Lot specific analysis will be required to confirm this assessment when building platforms have been selected.

#### 3.1.3 Static Settlement

The observed fill material within the infilled stream channel was generally very soft to firm or loose to medium dense and contained variable detritus (such as glass, metal, wood). These factors suggest that the placed material was not cleanfill and was not placed to engineering standards. Static settlement in the form of consolidation is therefore possible under loads associated with further fill placement or the proposed residential development. In addition to settlement of the stream channel infill, there was potential that the soft fill materials used in the area of the past effluent ponds may statically settle over time or when loaded during development.

#### 3.1.4 Stream Bank Regression

Where the meandering stream channel is present (those areas that were not previously filled), there was potential for stream bank regression over time. Stream bank heights varied from 3 m in the southeast to 12 m in the north, with some areas showing a clear slope break / crest, while others had a less distinct and rolling crest to the bank. Geomorphology of the stream banks suggested that there have been varied phases of instability over time.

### 3.2 Slope Hazards

#### 3.2.1 Landslide Potential

Mapping presented within the Upper Hutt City Council proposed district plan identifies the sloping areas of the site as having a high slope hazard. Site observations and knowledge of the typical failure mechanisms that occur across Wellington slopes, suggests that the most likely form of landsliding would involve shallow sliding of the surface soils on the underlying rock surface. Owing to the relatively low nature of the hills and reasonably shallow expected depths to rock, it is considered that these will typically be of a localised and shallow nature; however, there is geomorphological evidence of at least one large scale failure across the north-western extent of the site. The large landslide does not appear to show any evidence of movement during the time frame of the available historical aerial photographs, suggesting movement prior to 1951.

As a preliminary means to characterise landslide potential, LiDAR available through the Greater Wellington Regional Council was used to group the site into areas of similar gradients. For each slope gradient, a likelihood of instability has also been assigned as follows:

- Less than 17.5°: instability unlikely.
- Between 17.5° and 25°: instability possible.
- Between 25° and 32.5°: instability likely under earthquake or rainfall events.
- Between 32.5° and 37.5°: instability likely.
- Greater than 37.5°: instability expected.

#### 3.2.2 Rockfall Potential

The rock exposures were limited to those within formed accessways (forestry tracks and cuts), at the base of stream channels and along the broad ridge. No significant outcrops were observed on the side slopes and the potential for rockfall to be initiated was considered to be low. Further, the exposed rock comprised highly to completely weathered Greywacke sandstone which is highly fractured and more susceptible to localised frittering rather than large block release which is required for significant and damaging rockfall.

#### 3.2.3 Debris Flow Potential

Historical alluvial fans suggested some potential for debris flows. The likely initiation of debris movement and style of flow has been assessed by morphometrical evidence, using the Melton ratio (R) outlined by Welsh and Davies (2010), which suggests a debris flood hazard rather than a debris flow. A debris flood is defined as a very rapid flow of water, in a steep channel. While debris floods can be heavily charged with debris, they do not have the same concentration of material as debris flows and are typically much less destructive. Accordingly, the risk to future development posed by impact from debris flow initiation was considered to be low.

## 4 GEOTECHNICAL CONSTRAINTS MAPPING

For this project, the developers aim was to identify areas of the site that could be readily developed in a cost-effective manner, compared to those areas which would require extensive engineering to form suitable building platforms. Accordingly, a visual summary of the hazards in the form of a constraints map was considered to be the most useful approach to conveying this information. This approach combines our knowledge of past and present site conditions with a visual aid to guide future works.

In its simplest form, the constraints map considers interactions between site geology, geomorphological conditions and topographic conditions, and how this will impact the proposed development. The complexity of the constraints map can be varied based on the known site history and stage of proposed development.

For this case study, the geotechnical assessment was completed at a very early stage of the project, and accordingly the constraints map was tailored to provide a broad overview of the limitations to future development. Five risk classes were identified, ranging from areas with little to no limitations to future development; through to areas where complex engineering would be required in conjunction with development and consideration could be given to avoiding those areas. Site properties were identified for each of the five categories, considering both flat land and hill slope characteristics based on the hazard assessment. The risk classes are summarised in Table 1.

*Table 1: Risk Classes*

| Development Risk Class | Flat Site Characteristics | Hill Slope Characteristics | Limitations to Development |
|---|---|---|---|
| 1 | Areas of natural ground<br>Little to no liquefaction induced settlements | Low slope gradients (less than 17.5°)<br>No obvious evidence of instability | Little to no limitations to residential development (subject to foundation suitability) |
| 2 | Areas of minor filling (up to 1 m thick)<br>Liquefaction induced settlements of up to 25 mm under SLS conditions | Areas of moderate slope gradient (17.5° to 25°)<br>Areas of minor filling (up to 1 m thick)<br>May be evidence of instability following heavy rainfall or large earthquake events<br>No obvious evidence of instability | May require shallow earthworks to form a suitable building platform |
| 3 | Areas of moderate filling (up to 3 m thick)<br>Liquefaction induced settlements over 50 mm under SLS conditions. | Moderate to steep slope gradients (25° to 32.5°)<br>Instability is likely under earthquake or rainfall events (includes potential for inundation from upslope)<br>or<br>Some evidence of small scale instability | Will likely require specific engineering design to form a suitable building platform |
| 4 | Areas of moderate to major filling (up to 8 m thick)<br>Liquefaction induced settlements over 50 mm under SLS conditions. | Steep slope gradients (32.5° to 37.5°)<br>Instability is likely under earthquake or rainfall events (includes potential for inundation from upslope)<br>or<br>Evidence of large-scale inactive or relict slope instability | Will require specific engineering design and substantial foundations and / or earthworks to form a suitable building platform |
| 5 | Areas where liquefaction induced settlements are likely to be over 100 mm under SLS conditions | Steep slope gradients (greater than 37.5° from horizontal) and indications of recent instability<br>or<br>Evidence of large-scale, active slope instability | Complex or large-scale engineering works required to develop. Consideration should be given to avoiding these other areas owing to severe physical limitations that are likely to be difficult to overcome |

The risk classes were then mapped for the site, and the preliminary lot layout plan was overlain so that lots with a low risk to development can be clearly distinguished from those with greater risks, as shown in Figure 3.

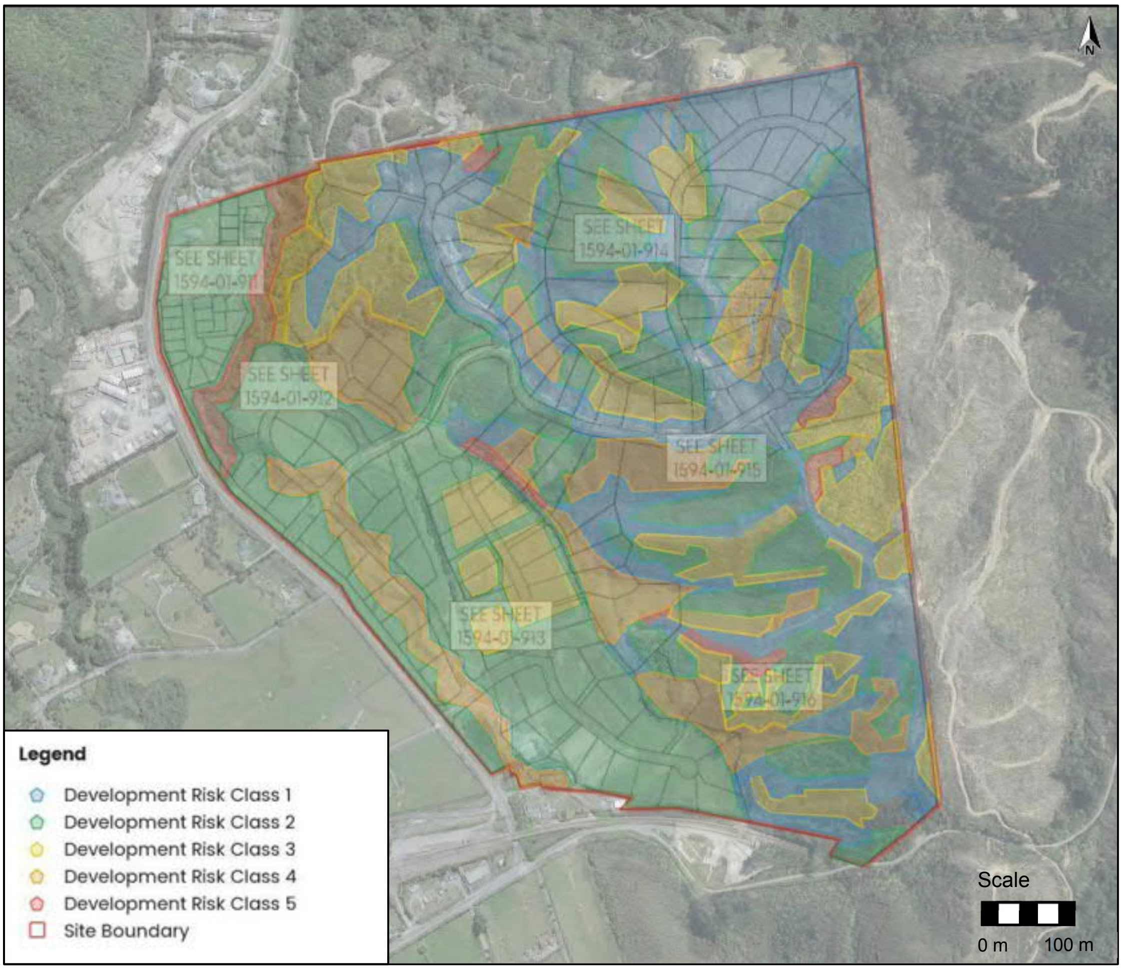


*Figure 3: Geotechnical Constraints Map*

In some areas the constraints map indicates higher development risk classes immediately adjacent to a lower risk category. Where that occurs, a lot-specific geotechnical investigation was recommended on the lower risk site to take into consideration the risk posed by the adjacent area.

## 5 CONCLUSION

Complex sites with many interacting geo-hazards require careful consideration as to the method of communicating associated risk to development works to avoid any hazards being overlooked. The use of constraints mapping provides a concise, typically single page, summary that can be readily interpreted by those without technical backgrounds. In this case study, the constraints map was found to be an invaluable tool for rapid assessment and re-evaluation of the subdivision lot layout.

## 6 ACKNOWLEDGEMENTS

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