GEOG309-23S2

Final Report

Erosion Susceptibility at Mt Vernon Park

Group 12

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Executive Summary

- Mt. Vernon Park is situated on the Port Hills in Christchurch, known for its susceptibility to erosion due to hillside terrain and local ground conditions.

- This project identifies areas susceptible to erosion in the Park and provides recommendations to reduce and mitigate the future risk of erosion.

- The study adapts a GIS-based approach, utilising a Digital Elevation Model (DEM) to analyse slope angles, extract slope zones, and identify erosional processes.

- The GIS analysis identified varying erosion susceptibility zones, with high-risk areas located in the northwest and northeast corners of the park. Erosional processes, including tunnel gully erosion, mass movements, and exposed bedrock, were successfully mapped, with confirmation from site visits and satellite imagery.

- Short-term land use management recommendations include stock rotation and confinement of grazing to drier slopes, while medium- and long-term land use management solutions involve three phases of focused grazing and land retirement of erosion-prone areas within Mt Vernon Park.

- Analysist of Corrosion Inhibitor Barrier stabilisation short term mitigation.

- Analysis of Vegetation and Contour Planting long term Mitigation.

- Land use Management and Mitigation plans provided to reduce and mitigate future erosion within the park.

Acknowledgements

Group 12 would like to acknowledge the support and contributions from the following individuals and organisations in the completion of this group report: Sam Hampton, Alan McDonald, The Port Hills Trust Board, and David Bell.

Introduction

Project Purpose/ Research Questions

Mt Vernon Park is situated on the Port Hills in Christchurch (Figure 1). Due to its hillside and local ground conditions, it is susceptible to erosion through fluvial processes (McMurtrie et al, 2017). This project identifies areas susceptible to erosion in the Park and provides recommendations to reduce and mitigate the future risk of erosion. Prevention of erosion in the Park helps keep the area safe for the public while minimising the sediment that enters waterways. Remediation actions, in partnership with restorative vegetation planting, can promote ecosystems for flora and fauna while reducing erosion impacts.

This research focuses on the question "What are areas that are susceptible to erosion at Mt Vernon? And how can the risk of future erosion be reduced and mitigated?" and is written for the Port Hills Trusts to support their land-use management. As the Trust does not receive a large income towards remediating the Park, short- and long-term mitigation strategies that are cost-appropriate are essential.

Study Area

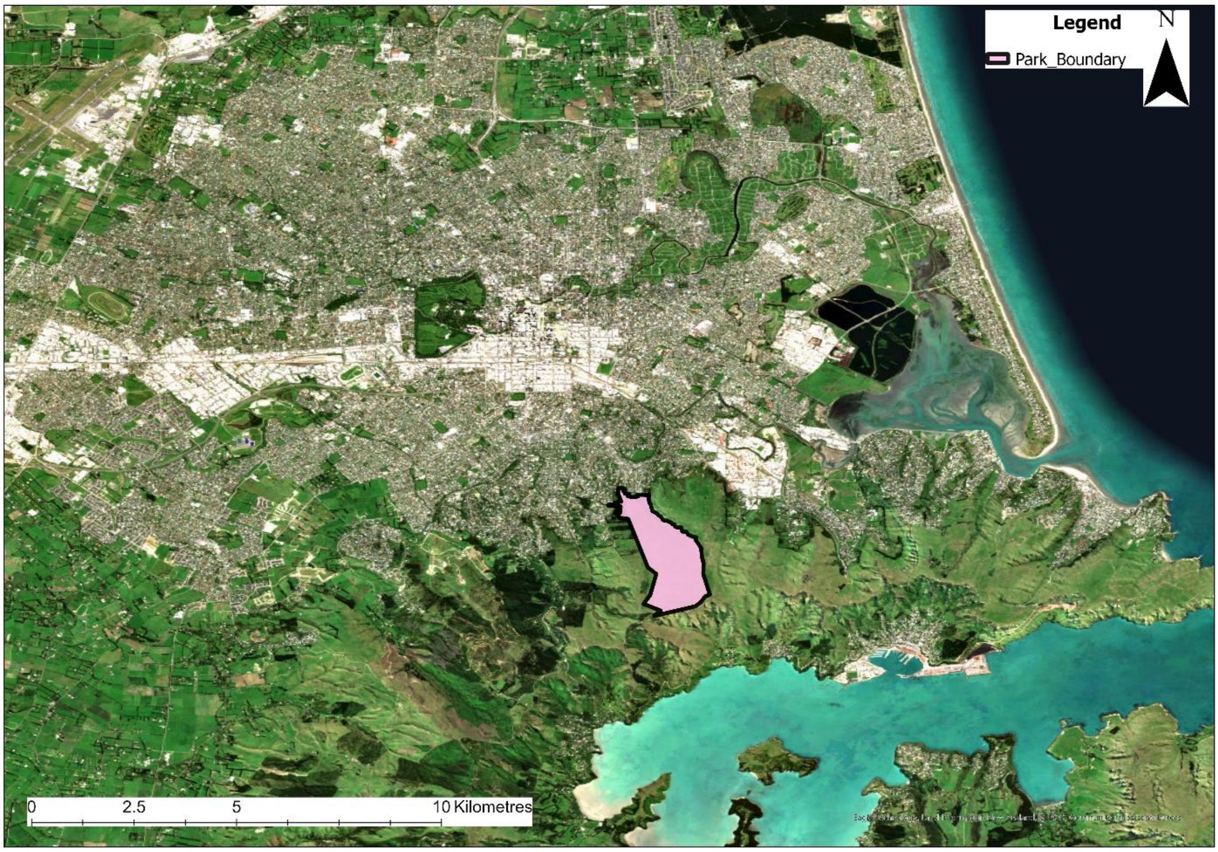


Figure 1: Mount Vernon Park's Boundary in relation to Christchurch.

Site Background

Mount Vernon Park is 235 hectares and is located amongst the Port Hills of Christchurch (Figure 1). The park was purchased for the people in 1985 after a successful campaign to raise funds and is currently open to the public, providing an area for multiple recreational uses on a day-to-day basis (Park Trust, n.d.). The land is currently used for recreational activities, with many walking and mountain biking trails within the park's boundaries. Stock grazing is persistent across the park, with limited fenced-off areas, allowing stock to roam freely. Current day income of the park is produced through leasing the land to the farmer who controls the stock and by the Trust receiving grants from various places.

Geologic Setting

The Port Hills are a 12-million-year-old remnant of the Lyttleton Volcano crater (City Council, n.d.). The Lyttleton Volcano was formed 10-11 million years ago, Akaroa was the other main volcano of Banks Peninsula, which was active some 8-9 million years ago. Much of the eruptive activity was Hawaiian-style, with a sequence of basalt lava flows built up on previous flows (Brown et al, 1995). The volcanic rocks of the Port Hills are of late Miocene age, and the unconsolidated deposits underlying the coastal Canterbury Plains at a depth of 400m are late Quaternary in age (Brown et al, 1995). Weathering factors have had a prominent impact on the shaping of the landscape between what it once looked like 11-12 million years ago and the current day. Mount Vernon Park, alike the remainder of the Port Hills is comprised of mostly Loess soil. The loess deposited in the Canterbury region originates from the Southern Alps greywacke which has been ground into fine particles and over time been transported by prevailing north-westerly winds (McMurtrie et al, 2017). The accumulation of loess has influenced the current shape and nature of the complex terrain across Mount Vernon and the Port Hills. 'Loess soil is highly erosional prone because of its fine, loose particles that lack cohesion and its tendency to erode when wet' (Pye K, 1995).

Methods

The novelty of this study lies in the adaption of a pre-GIS study in a similar landscape and soil environment of the Port Hills, in the neighbouring area of Mt Pleasant, Sumner Region (Trangmar & Cutler, 1983). Trangmar and Culter's (1983) study used values that are easily recognised and extracted within GIS (Figure 2). By adapting the parameters to local sites conditions (topographic heights, slope ranges), this study brings this landscape classification system and erosion process relationships to a GIS platform.

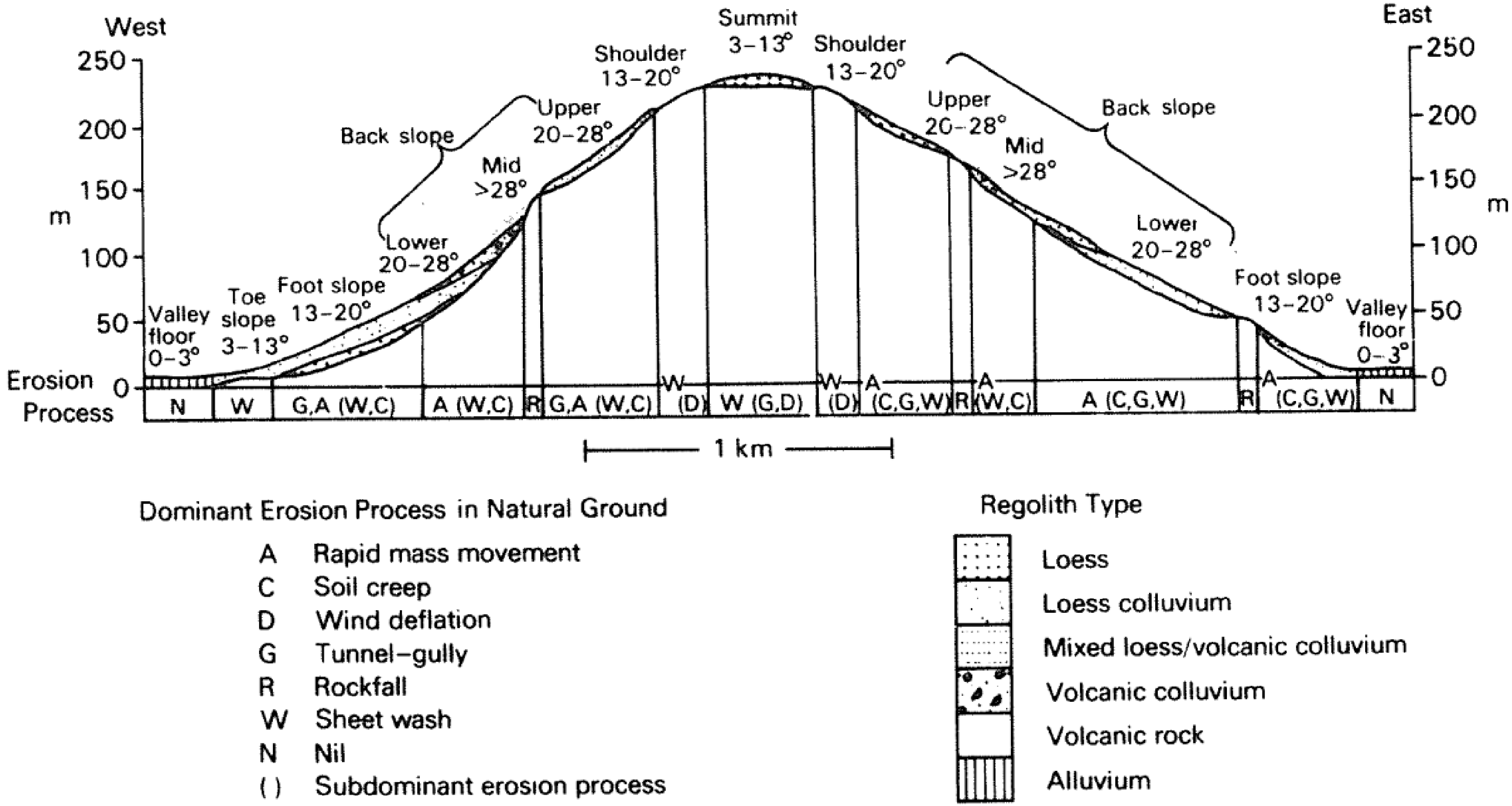


Figure 2**:** Generalised Ridge Cross-Section Showing Relationships Between Landforms, Slope, Regolith Types and Erosion in The Sumner Region. Sourced from Trangmar & Cutler (1983).

GIS Database

Spatial data is a powerful tool that can help in decision-making to ensure best practice. Creating a GIS database allows all data to be stored in one location and becomes easily accessible within ArcGIS Pro. This database will store any analysis, extraction, or digitising of data, and can be provided to the Trust for their use in the future.

GIS Analysis

Trangmar and Culter (1983) identified the erosion types occurring within slope ranges (Figure 2). Using GIS, the slope values at Mt Vernon could be extracted to identify different slope zones and therefore be related to erosion processes. To perform this analysis a 1m Lidar-based Digital Elevation Model (DEM) was used, sourced from LINZ (Land Information New Zealand, 2021). Using ArcGIS Pro the slope tool was used to analyse slope angles from the DEM. Slope angles were then classified into different ranges, guided by the relationships of Trangmar and Culter (1983).

Supporting Layers and Data

To support this study and aid the Trust in managing the Park other feature were extracted or digitised within GIS. A stream network was derived from the high-resolution DEM. Scans of an earlier Soil Map and Farm Map was also georeferenced. Features important in understanding causes of erosion susceptibility and identifying erosion management were also digitised, these included tracks, roads, car parks, ponds, fence lines and culverts.

Linking GIS Analysis to Geomorphology

To identify specific erosional features, slope data was utilised to formulate a geomorphic map of the park. Comprehending the project's objective, the appropriate scale for conducting geomorphic mapping was crucial when determining the method of data collection. Geomorphic mapping broke the landscape into different categories (Bathrellos et al., 2011) and integrated map layers to display geological hazards (Fedeski and Gwilliam, 2007). Earlier GIS analysis, slope and surface imagery was utilised in both the desktop and on ground mapping of the geomorphology.

Erosion Processes, Slope and Geomorphology

GIS

The three primary erosional processes that were identified and mapped included tunnel gully erosion, mass movements, and exposed bedrock, which can lead to rockfall. Erosional processes were represented by drafting polygons within GIS. This approach facilitated the colour-coding of each erosional process.

The methodology involved utilising slope angle data, satellite imagery, and topographic contour lines to identify the various geomorphic features. Tunnel gully erosion was pinpointed by simultaneously using the slope angle GIS layer and topographical contour lines, as tunnel gullies were found to generally run perpendicular to these contours (Figure 3). Satellite imagery proved less effective for identifying small-scale tunnel gullies due to typically being covered in vegetation cover, or not clearly expressed at the surface.

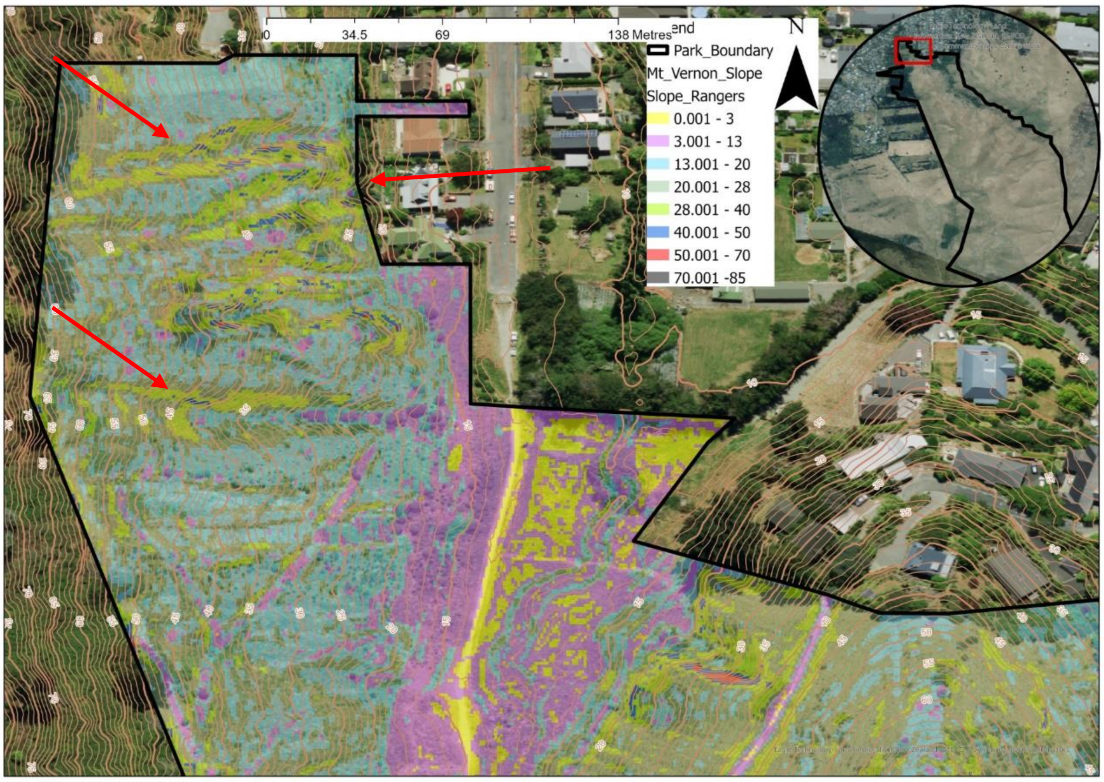


Figure 3: Northern End of the Map with the Red Arrows Highlighting the Tunnel Gully Erosion on the Slope Angle GIS Layer.

Exposed bedrock, with its pronounced relief in the landscape, was identified using the slope angle layer (Figure 4). Mass movement, primarily slips, were mapped using a combination of the slope angle layer, contour lines, and satellite imagery (Figure 5). These movements were identified by either a head scarp without debris or a head scarp with hummocky block movement beneath.

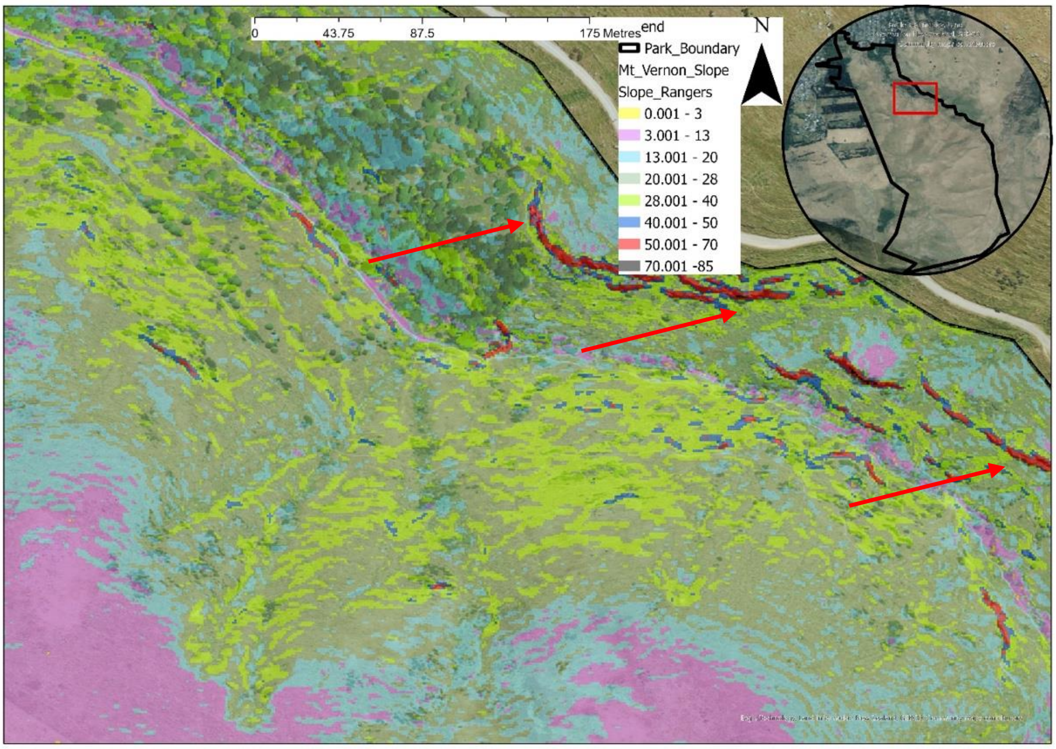


Figure 4: North-Eastern Side of the Map with the Red Lines Highlighting Exposed Bedrock on the Slope Angle GIS Layer.

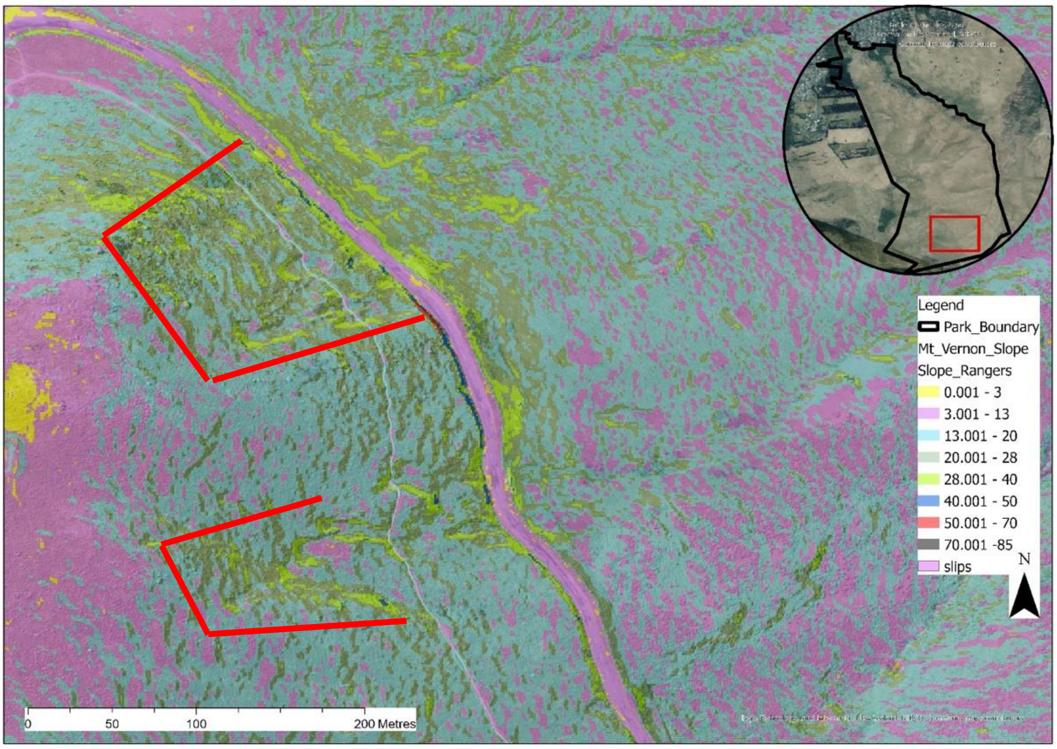


Figure 5: South Side of the Map with the Red Lines Highlighting Mass Movements on the Slope Angle GIS Layer.

Site Visit

To support the interpretation of the mapped erosional features at Mt. Vernon within the geomorphic map, a field inspection became imperative. Following Brunsden et al (1975) guidelines, a specific geomorphic hotspot zone at the northern end of the Park was selected for an on-site visit (Figure 6), with the objective of this visit to verify mapped tunnel gully erosion, exposed bedrock, and mass movements. This visit also provided an opportunity to record any supplementary information and details of land-use and drainage management.

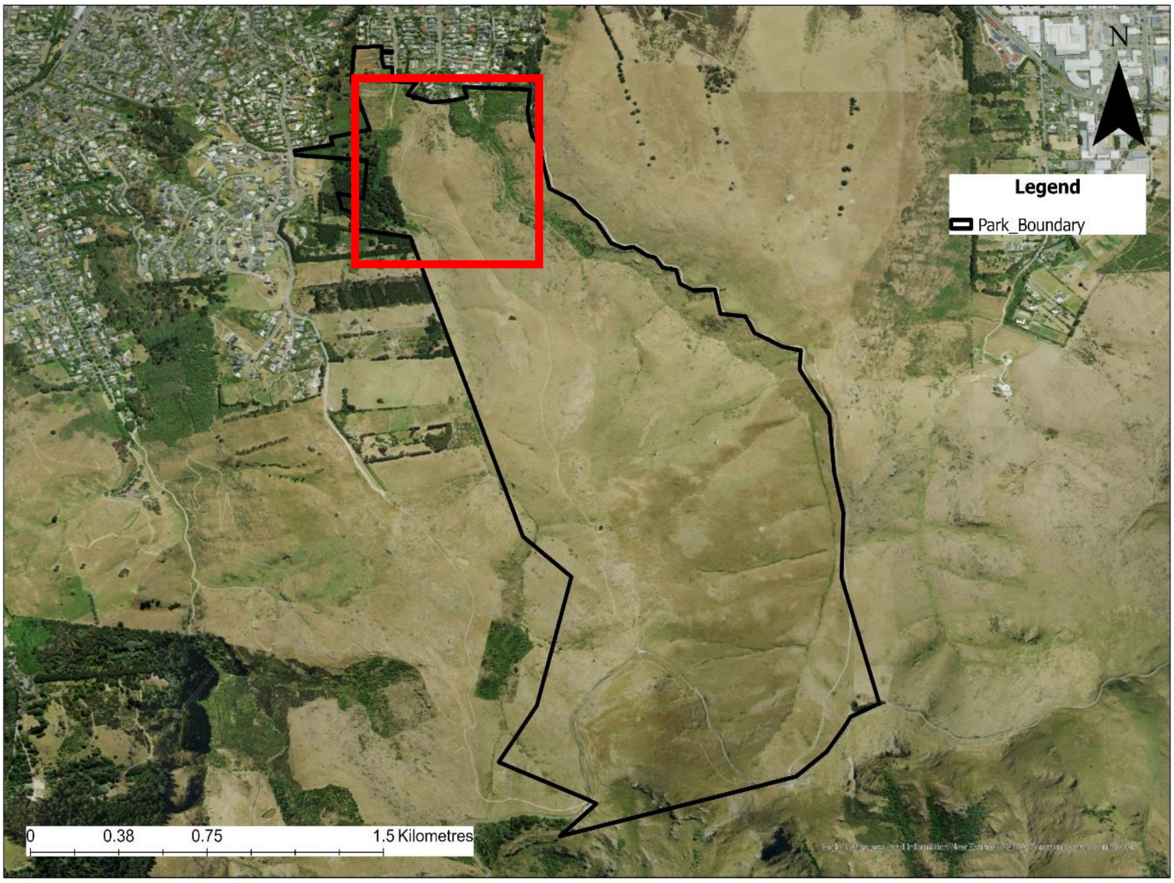


Figure 6: Site Visit Location, Indicated by the Red Box.

In combining the GIS analysis, geomorphology, and the site visit a land management map was constructed in ArcGIS Pro. Providing a centralised data store and visualisation to inform decisions around the management of the Park. Further, in creating this map in ArcGIS Pro, hypothetical land management practices could be implemented, i.e., new fence lines, creating new grazing blocks or land retirement. In this instance, GIS offers the easy calculation of new block size and the required length of new fence lines. This analysis gives quantifiable numbers which aid in costings and land management decisions.

Results

GIS Analysis

The GIS analysis has provided meaningful results that help understand erosion at the Park. Figure 2 by Trangmar and Culter (1983) shows the dominant and subdominant erosion process and is useful in understanding the erosion process that will be present at the Park. Figure 7 shows different slope angles within the Park area. These slope angles have been classified into eight different ranges based on the findings of Trangmar and Culter (1983). By classifying the slope angles into different ranges, the dominant erosion process in natural ground can be identified. The Figure 7 shows that the land on the main spur has low erosion susceptibility, as shown by the yellow and pink colours. Figure 7 shows that the Northwest corner of the park and the valley slope facing Northeast in the Northeastern area of the park have high susceptibility. The green colours indicate the dominant erosion processes present in tunnel gullies and rapid mass movement.

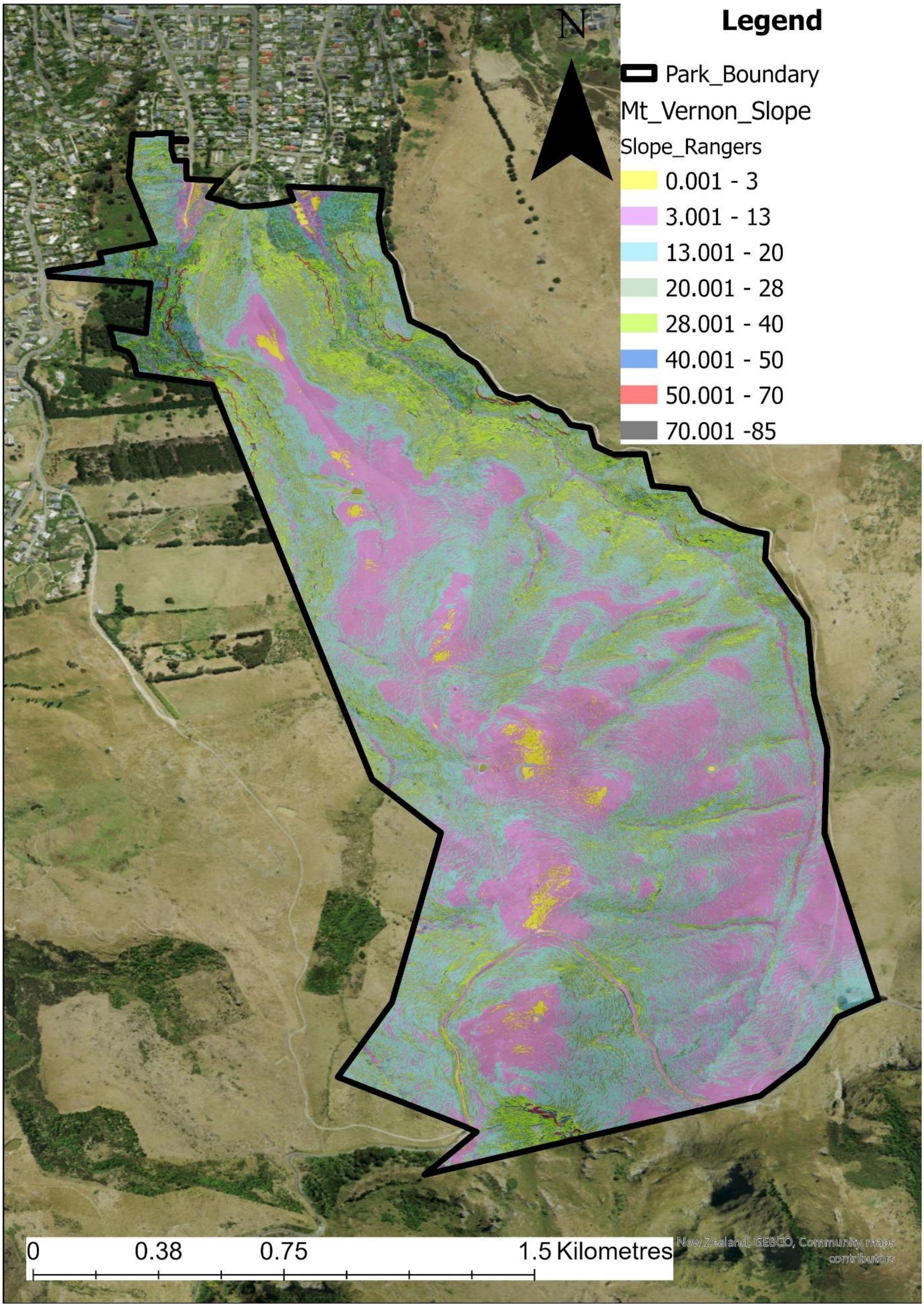


Figure 7: Map showing the slope angles classified into eight ranges based off the findings of Trangmar and Culter within the Mt Vernon Park.

Figure 8 shows the stream network within the Park which was derived from the DEM. Showing the key drainage points within the park, the fence lines have also been plotted to show that these fences do not exclude stock from anyway of the waterways identified.

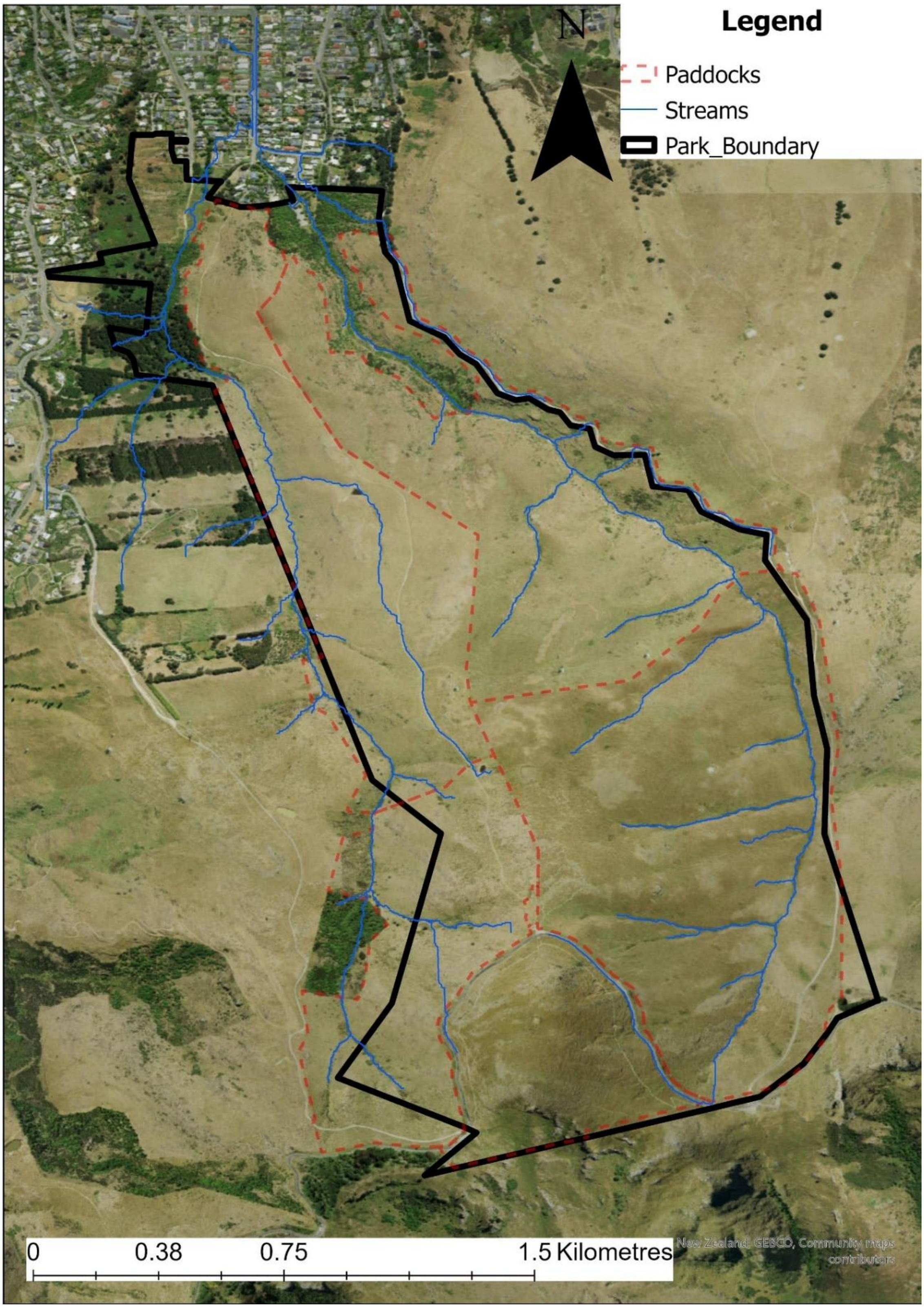


Figure 8: Map showing the stream network extracted from DEM data within the Park, current farm fence lines have been mapped to show farm blocks.

The features extracted and digitised within the park on GIS can be seen in Figure 9. These features help in understanding natural and human activities that are influencing erosion susceptibility at the Park. The culverts in Figure 9 show the current management infrastructure in place to reduce erosion. The different tracks show the main routes that are used by different groups such as the public, farm workers and stock.

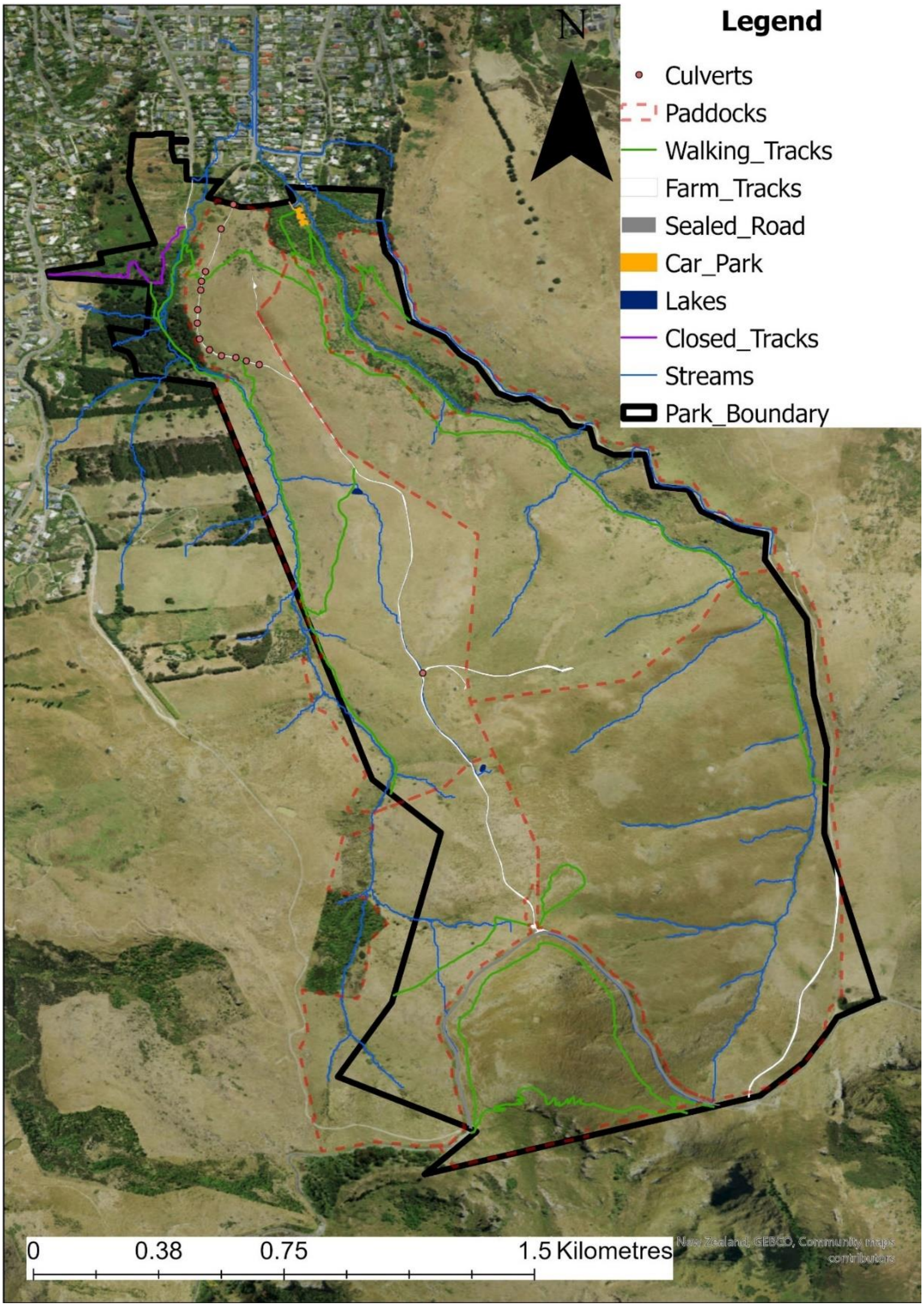


Figure 9: Map presenting natural and man-made features within the park that influence erosion susceptibility and park management.

Erosion Processes, Slope and Geomorphology

GIS

Utilising the GIS-geomorphology method for mapping allows for a valuable comparison with data from the Trangmar and Cutler (1983) study. Tunnel gully erosion was mapped throughout the entire back slope region at Mt. Vernon, aligning with the findings of the study by Trangmar and Cutler (1983). The geomorphic map has identified a total of 10.1 hectares of the park affected by tunnel gully erosion (Figure 10).

Exposed bedrock within the park was mapped across all slope regions, though not all of it is susceptible to erosional processes such as rockfall (Figure 10). The exposed bedrock most prone to erosional threats was primarily concentrated in the mid-back slope regions, where the slope gradient exceeds 50 degrees. However, a limitation of the mapping process arises from including all exposed bedrock, rather than just the portions susceptible to rockfall. Consequently, it becomes challenging to determine the specific area of highly susceptible rockfall terrain.

The mapped mass movements varied in size and type, predominantly concentrated in the lower and upper back slope regions, consistent with the study by Trangmar and Cutler (1983). These mass movements covered an area of 0.4 hectares within the park (Figure 10).

Site Visit

The primary goal of the site visit was to physically locate instances of tunnel gully erosion, exposed bedrock, and mass movements within the northern hotspot zone of the park. Tunnel gully erosion was identified at all the locations previously marked on the geomorphic map (Figure 11), though it was challenging to spot due to heavy vegetation cover (Figure 12). The map served as a valuable reference in guiding the search.

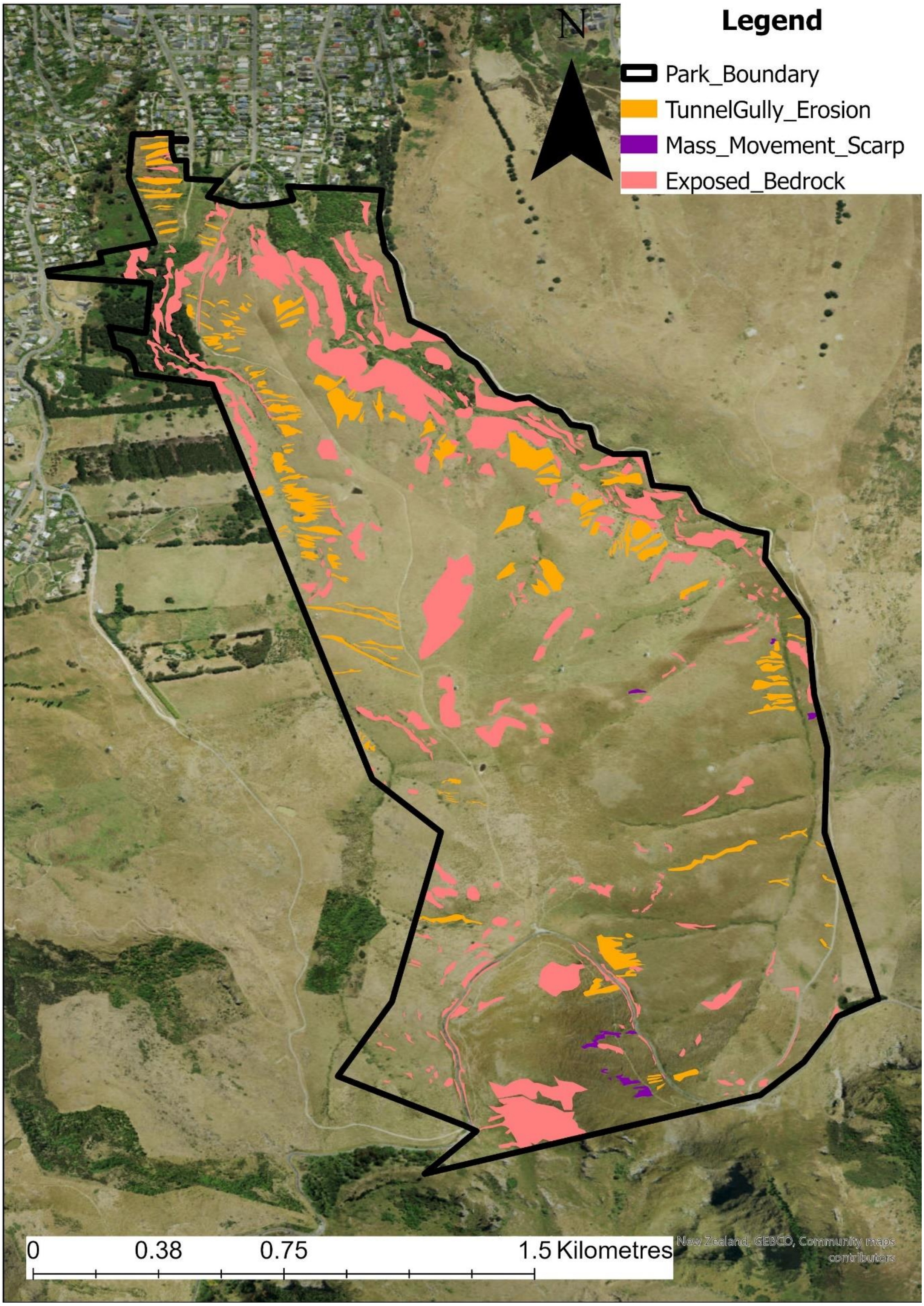


Figure 10: Geomorphic Map, erosion features have been determined from the Slope Map (Figure 7) and the use of satellite imagery.

Figure 11: Tunnel Gully Holes at Mt. Vernon, Indicated by the Red Arrows. The Measuring Staff is 1 m for Reference.

Figure 12: Collapsed Tunnel Gully Erosion at Mt. Vernon Park, Indicated by the Red Lines. The Measuring Staff is 5 m for Reference.

During the visit, volcanic bedrock, compromised of stratified lava flow sequences in the form of outcrops, ranging in height from 1 to 10 meters, was observed. These outcrops exhibited various platy fabrics, joint sets, and fracturing (Figure 13). Furthermore, scattered throughout the summit and shoulder slope regions were boulders of rock. Significantly, the exposed bedrock identified in the field closely matched what had been previously mapped using the GIS-geomorphology method.

Figure 13: Exposed Lava Flow Outcrop at Mt. Vernon, Platy Fabric, Joints and Fracturing Indicated by the Red Arrows. The Measuring Staff is 1 m for Reference.

The specific area under examination within the park revealed no previously mapped mass movements on the geomorphic map. However, during the visit, a small mass movement was identified downslope from the farm track (Figure 14). This particular event appeared to be an earth flow and is recent (Winter of 2023 has been relatively wet), which accounts for its absence in satellite imagery.

Figure 14: Mass Movement at Mt. Vernon, Indicated by the Red Lines. The Measuring Staff is 2 m for Reference.

Discussion

Part 1: Application of Trangmar and Cutler (1983) Model to ArcGIS

Comparison of the Two Studies

The study by Trangmar and Cutler (1983), employed slope value parameters to create cross-sections that assigned each erosional feature to a specific region on the slope (Figure 5). This approach effectively illustrates how changes in elevation impact these erosional features. The geomorphic map and the subsequent site visit validated the findings of this study, confirming the suitability of the established parameters for the current project. Consequently, the project could employ similar parameters to generate cross-sections. Soil maps do exist at the park and show the same soil units written about in the Trangmar and Cutler (1983) study. This is important as the site-specific soils are critical when using the slope parameters to define the associated erosion processes.

A limitation of the Trangmar and Cutler (1983) study was that it only provided a generalised cross-section, preventing a detailed comparison of the variations in elevation between the two projects. By comparing the two cross-sections in this study it is possible to see how the erosional zones change with elevation.

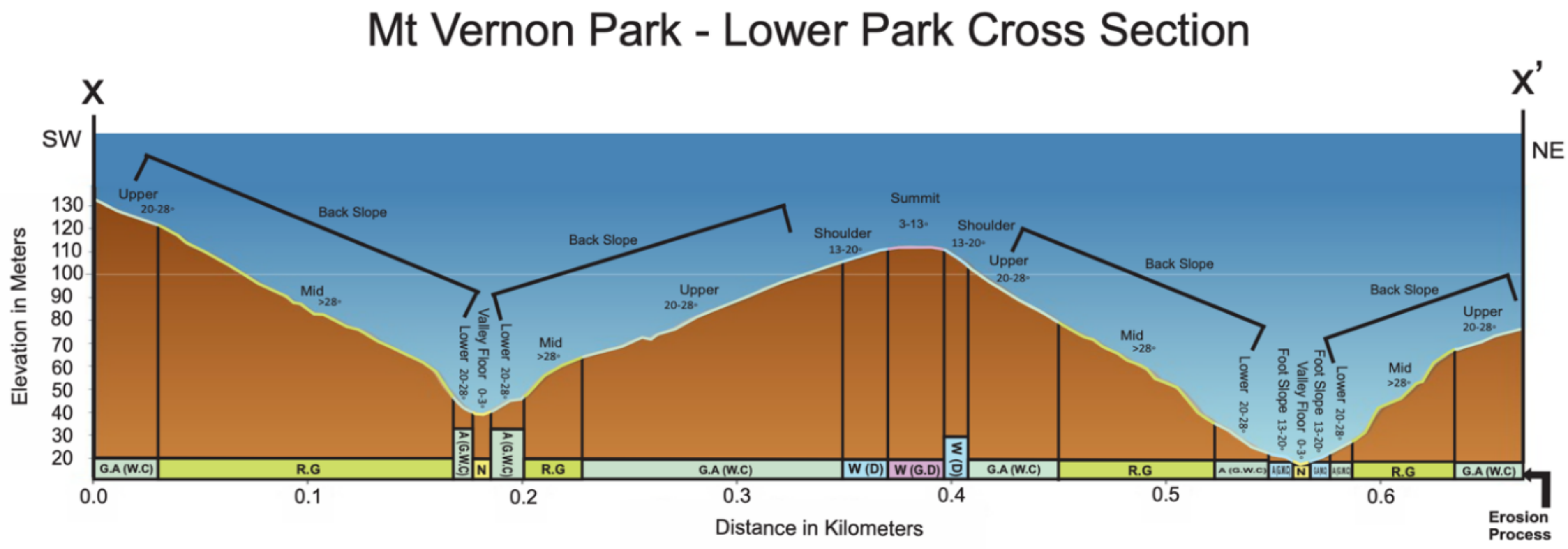
Slope Variances

The project aimed to assess the differences between the upper and lower sections of the park to determine variations in erosional zone sizes (Figures 13 & 14). It was observed that as elevation increased within the park, the slope gradient angle generally decreased. Consequently, the size of each erosional zone changed with varying elevations. Notably, in comparison to the Trangmar and Cutler (1983) study, the mid-back slope regions in this project covered a much greater area. These larger zones contributed to an increased risk of tunnel gully erosion and rockfall occurring.

Wet vs Dry Slopes – Inherited Relationships

The cross-sections (Figures 15 & 16) developed in the analysis provided an opportunity to infer what the subsurface geology is doing. The geology at Mt Vernon is comprised of multiple layers of igneous strata (Timm et al., 2009; Hampton and Cole 2009).

Discussions with volcanologist Dr Sam Hampton, have enabled inferred strike and dips to be projected within interpreted cross-sections (Figures 17 & 18). Stratified lava flow sequences are permeable, which enables water to traverse through pore spaces and joints within the strata (Qin et al., 2023). Additionally, the rock layers exhibit a slight dip toward the northeast direction (GNS Science, n.d.). Consequently, water infiltrating the southwestern slopes gradually channels towards the north-eastern slopes, indicating the flow direction. This insight allows for the classification of slopes on either side of the spur as either "Dry Slopes" or "Wet Slopes." The "Wet Slopes" classification implies there is a higher chance of natural springs forming as the water resurfaces (Hampton et al., 2018). It is very important to maintain monitoring of these springs to prevent any further slope saturation.

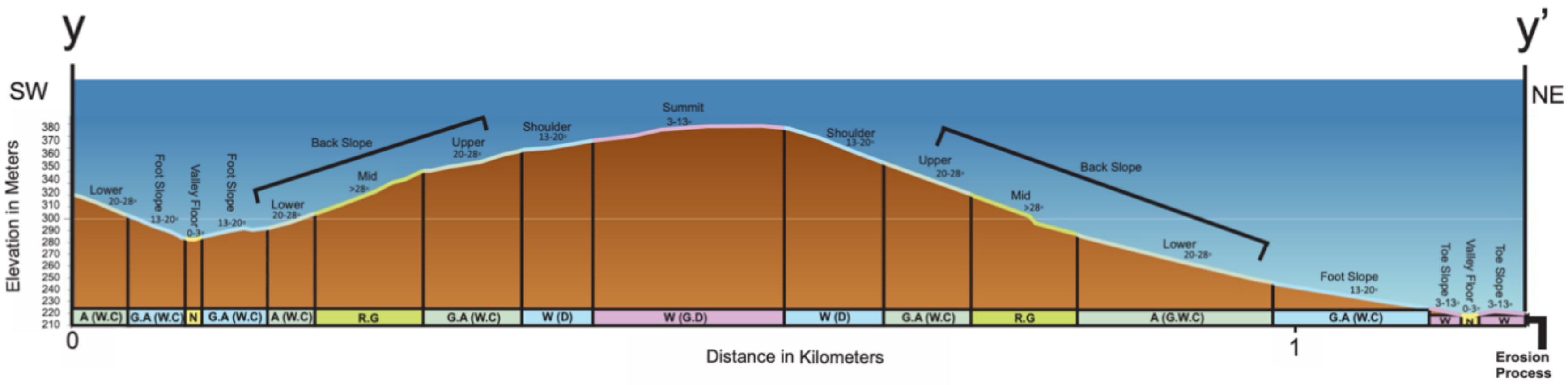


Dominant Erosional Process in Natural Ground

A	Rapid Mass Movement
C	Soil Creep
D	Wind Deflation
G	Tunnel-Gully
R	RockFall
W	Sheet Wash
N	Nil
( )	Subdominant Erosion Process

Figure 15: Lower Park Cross-Section Showing Relationships Between Landforms, Slope, And Erosion at Mt. Vernon Park.

Mt Vernon Park - Upper Park Cross Section



Dominant Erosional Process in Natural Ground

- **A** Rapid Mass Movement
- **C** Soil Creep
- **D** Wind Deflation
- **G** Tunnel-Gully
- **R** RockFall
- **W** Sheet Wash
- **N** Nil
- **( )** Subdominant Erosion Process

Figure 16: Upper Park Cross-Section Showing Relationships Between Landforms, Slope, And Erosion at Mt. Vernon Park.

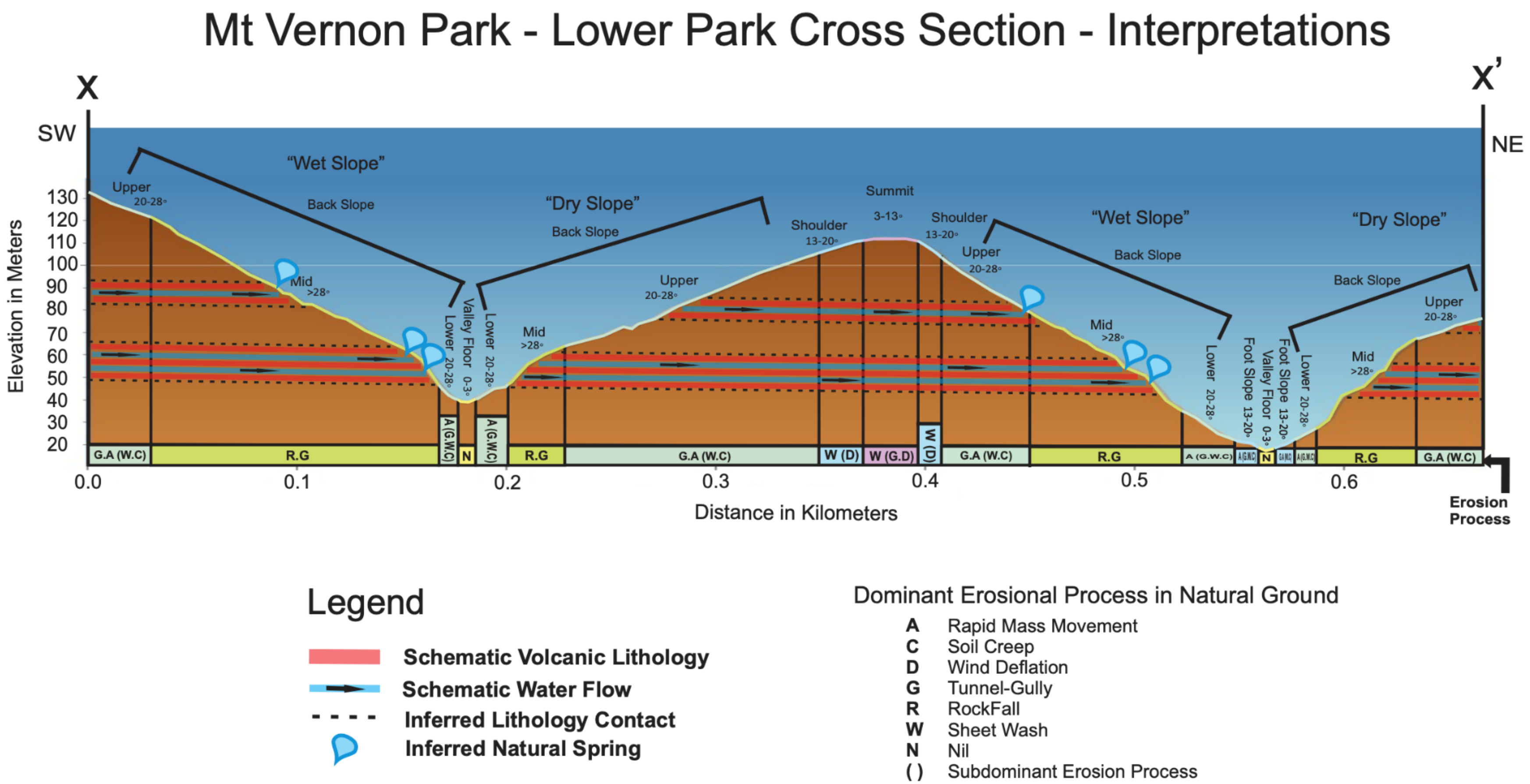


Figure 17: Lower Park Cross-Section Showing Relationships Between Landforms, Slope, And Erosion, with the Inferred Red Lines Serving as Indicators of Ancient Lava Flows at Mt. Vernon Park. Rock Layers Exhibit a Slight Dip Toward the Northeast Direction (Hampton and Cole, 2009).

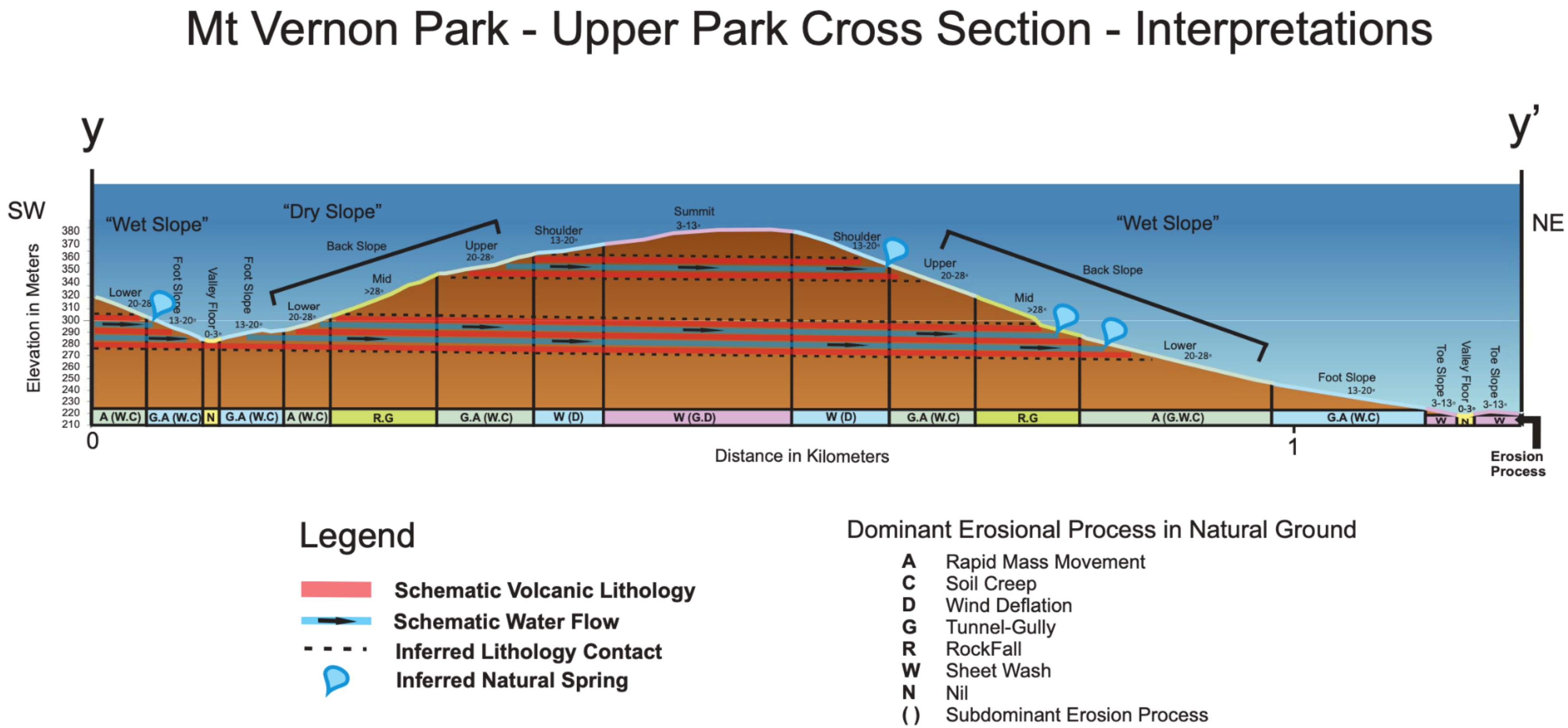


Figure 18: Upper Park Cross-Section Showing Relationships Between Landforms, Slope, And Erosion, with the Inferred Red Lines Serving as Indicators of Ancient Lava Flows at Mt. Vernon Park. The Rock Layers Exhibit a Slight Dip Toward the Northeast Direction (Hampton and Cole, 2009).

Ability to Identify Landscape Features and Relationship to Erosional Process

The results and comparisons show that using the findings of Trangmar and Culter (1983) has been effective in identifying erosional processes at the Park. Without the knowledge of Trangmar and Culter (1983), the methods used in this study would have not been as accurate. The report by Trangmar and Culter (1983) was performed in the Sumner Region located near the Park. The parameters from Trangmar and Culter (1983) could then be directly applied to Mt Vernon as the same underlying conditions are present. To use Trangmar and Culter’s (1983) findings with a modern GIS approach, the key data needed was the DEM which can be sourced easily. Requiring no other major data gathering, saving valuable time given the project's time frame. The erosional processes identified in ArcGIS Pro by adopting the methods of Trangmar and Culter (1983) has effectively identified erosional process present. This was confirmed by the site visit and the use of satellite imagery. By incorporating the work of Trangmar and Culter (1983) the project applied a modern GIS approach which provided an accurate understanding of erosion at the Park in the short time frame.

Future Methods

While adopting the report of Trangmar and Culter (1983) has been very effective in identifying the erosion process at Mt Vernon Park, there are other methods available. These methods may be useful for the Trust if it wishes to continue further analysis into erosion. The revised universal soil loss equation (RUSLE) can be used to produce erosion rates and water flow patterns driving erosion (Pijl et al., 2020). This type of analysis requires more inputs which can be more time-consuming to collect. Some of the key inputs include rainfall excess rate, surface roughness, soil samples, organic matter values and soil structure. Studies in Western Greece and in the Himalayas showed how valuable the RUSLE can be in understanding soil loss (Michalopoulou et al., 2022)(Romshoo et al., 2021). Lidar differencing is also a common GIS method to calculate loss and understand erosion, this can be done by comparing two Lidar datasets (Open Topography, 2023). LINZ has a 1m DEM from 2015 and another from 2021, by comparing the differences between these datasets would provide an accurate view of soil loss and erosional areas (Land Information New Zealand, 2021). Sediment loss has major impacts on the catchment ecosystem downstream and by quantifying soil loss the damage can be understood.

Part 2: Land use Management Recommendations for Mt Vernon Park

Overview of Landscape Zones

Mt. Vernon Park serves recreational and agricultural purposes with a network of trails, including a central farm track providing access to Summit Road, and walking tracks that extend along the northeast and southwest valleys to Mt. Vernon's summit (See Figure 9). The park's existing fence lines divide it into five large blocks where sheep graze freely throughout, with two areas in the park's lower reaches retired from farming (Figure 19**)**.

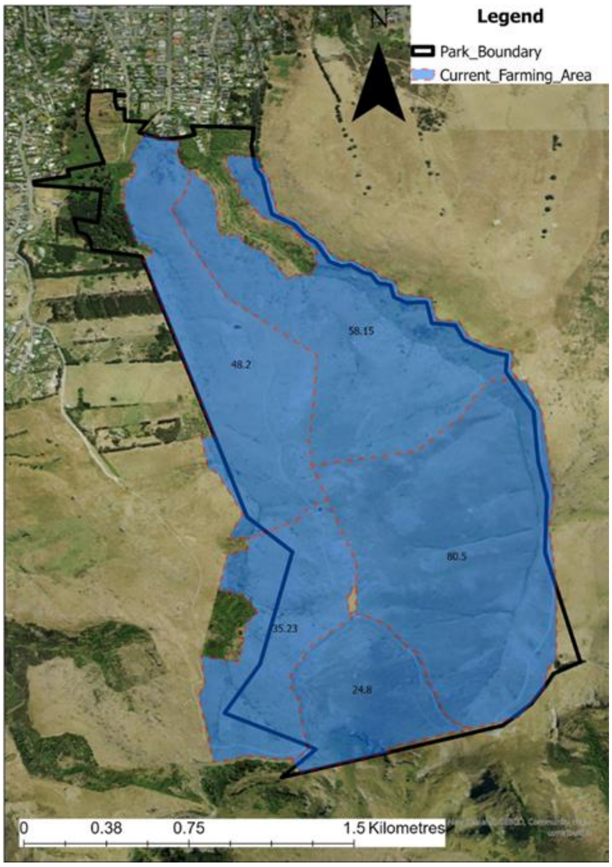


Figure 19: Farm Map showing the current farming blocks within Mt Vernon Park and their respective area size in hectares.

Areas of Concern and Associated Erosional Processes

Understanding erosion susceptibility is important for effective land management in the Park. Slope analysis reveals steeper slopes (28-40 degrees), are most vulnerable to erosion (See Figure 7). Soil erosion is most common on slopes steeper than 25 degrees (NZ Landcare Trust, 2019). The highest levels of tunnel gullying are observed in valleys on either side of the main ridge, particularly in the lower park section (See Figure 7). High erosion is evident in the northeast valley near the lower farm track. The lower half of the park, around the southwest valley, also experiences heightened tunnel gully erosion (See Figure 7). The top block on Mount Vernon's summit holds cultural significance as it maintains a relationship with Te Hapu o Ngāti Wheke between the Port Hills Trust. This area contains stock and is susceptible to tunnel gully erosion and mass movement (slips evident from erosion scarps (See Figure 7)). Another area of concern is the blocks along the southwest valley, which contains a waterway flowing through them to the park's lower reaches (Figure 20). These two large southwest blocks are accessible to grazing stock, raising concerns about potential sediment contamination in the nearby waterway. Sheep treading can compact soil, forming established pathways as they graze and forage (NZ Landcare Trust, 2019). This compaction reduces soil permeability, leading to heightened surface water runoff during rainfall, with the potential consequence of carrying soil particles into the adjacent waterway (NZ Landcare Trust, 2019).

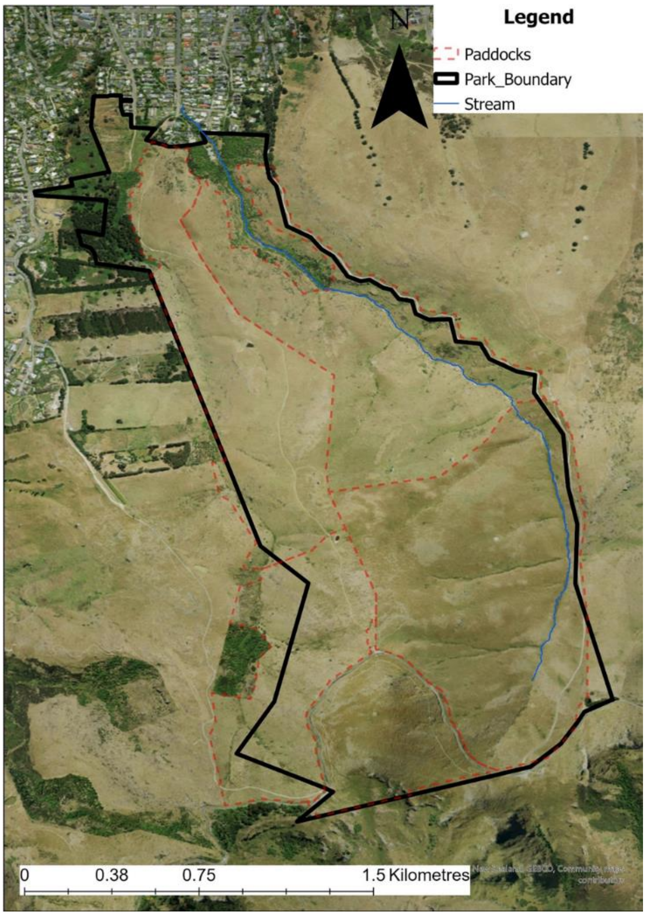


Figure 20: This map highlights the main outlet stream for water within the Mt Vernon Park Area.

Land Use Management Overview

Stock Management

Effective stock management in Mt. Vernon Park is vital to reduce erosion risks related to sheep grazing. Low stocking numbers are typical within Mt Vernon Park, but proper grazing practices are essential as recommended by the Christchurch City Council Waterways, Wetlands, and Drainage Guide (Christchurch City Council, 2003).

The impact of stock grazing on erosion depends on soil moisture and slope steepness (Pereira et al., 2023). Soil moisture influences stock grazing suitability, as saturated slopes weaken soil structure, leading to soil degradation and increased erosion when subject to grazing (Penny, 2016). Implementing strategies like multi-paddock management and rotational grazing can protect the soil by allowing stock exclusion from areas with poor soil conditions (Pereira et al., 2023).

To minimize hill slope erosion, it is crucial to maintain low stocking densities, preferably below 27 animals per hectare (Pereira et al., 2023). Steeper slopes are more susceptible to erosion due to increased shear stress and reduced soil stability (Penny, 2016). This emphasizes the need to exclude stock from these areas. In the Park, stock treading can open tunnel gullies and further disrupt soil in steeper erosion-prone areas. Stock can also create pathways that function as drainage channels during storms, exacerbating erosion, particularly on steeper slopes (NZ Landcare Trust, 2019). Excluding stock from areas with slopes exceeding 25 degrees is an effective strategy to mitigate hill slope erosion (NZ Landcare Trust, 2019).

Land Retirement

Land retirement is another effective land use management strategy within the Park. Retiring certain areas, particularly from grazing can reduce erosion and enhance the park's ecological integrity. Adding new fencing to existing fence lines is recommended to create new blocks, which keep stock within suitable grazing areas. Native vegetation can be planted in retired areas to increase soil stability (Emadi-Tafti et al., 2021).

Revegetation

Stock should be excluded from regenerative planting zones, as areas with regenerative planting are crucial for soil retention, runoff prevention, and moisture absorption (Víctor Hugo Durán Zuazo & Carmen Rocío Rodríguez Pleguezuelo, 2008). Slopes over 25 degrees need vegetative cover such as trees to increase long-term slope stability (NZ Landcare Trust, 2019). Without the right level of vegetative cover, severe erosion events are expected to occur at least once every 10 years (Christchurch City Council, 2003).

Local Stabilisation

Short Term Mitigation Methods

Short term mitigation and Stabilisation methods for Mt Vernon Park conclude to be more time efficient, however cost effective, but will only stabilise and mitigate areas of erosion within the park for a minimal period (See figure 22). The most appropriate and reasonable short-term method of mitigation for the park is barrier stabilisation in association with ‘corrosion inhibitors. Author’s A. Neville and C. Wang researched erosion mitigation by corrosion inhibitors (*Erosion-corrosion mitigation, 2009*). Programming and submitting tests experimentally to analyse corrosion inhibitors in solid and liquid environments to determine whether the impact of metal, steel or wooden fittings embedded within the ground would increase the rate at which soil erodes around the fittings, along with the emission of carbon dioxide from these fittings or reduce the rate of erosion and stabilize surrounding soils within the environment.

The article expresses ideal research for mitigation and reduction strategies that could potentially be put in motion across Mt Vernon park in prediction of upkeeping and restoring the park’s physical and historical area. The article is focused and prioritised testing carbon steel embedment’s of up to 5mm in thickness. Some experiments involved the steel embedment’s to be treated or soaked in sulphur, nickel, or phosphorus; other steel fittings were not soaked or treated. All fittings were embedded under the same force of pressure. The pressure, “701 capacity of atmospheric pressure (Erosion-corrosion mitigation, 2009)”. This pressure was to replicate a fitting embedded for long periods of time under exposed and weathered environments, such as Mt Vernon Park. The fittings were embedded for periods of two hours to replicate an applaudable period of time. The experiments also set to acknowledge if the fittings, treated or not, were of a safe and of substantial strength that could be sustainable to reducing and mitigating erosion in areas of soil with high susceptibility, accompanied by high public trafficked areas also.

Long Term Mitigation Methods

Long term mitigation and remediation methods for Mt Vernon Park are more time impending to implement and complete, economically trialling, but furthermore successful and beneficial for the park's future (See Table 2). The most appropriate method for the landscape, ground conditions, and geomorphology of the park is mitigation by vegetation and contour planting. The article '*Hillslope Erosion Mitigation: An experimental proof of a nature-based solution (Hillslope Erosion, Sustainability, 2021)*' compared and tested the areas during rainfall, post rainfall and on during dry periods incorporating the geomorphological factors to determine the predictability of erosion susceptibility to different methods of mitigation and reduction in erosion; with methods such as increasing vegetation coverage and reducing agricultural grazing. The article concludes "in terms of eroded material, the use of vegetation coverage up to thirty centimetres in height reduced soil erosion up to three hundred times higher than bare soil and ground conditions".

Proving vegetation rooting systems can withstand substantial pressures. Associating with this research is the article *'Potential effectiveness of low-density plantings of manuka as erosion mitigation'* written by M. Marden, S. Lambie, and C. J Phillips (*Effective plantings of low-density manuka as an erosion mitigation, 2020*). Testing and comparing low-density plantings of Manuka trees to mitigate erosion susceptibility in the steep areas of topography in the Hawke's Bay region of New Zealand. The article explores the effectiveness of planting manuka trees on steep and hillslope conditions susceptible to soil erosion (See Figure 22). With geomorphology, hillslopes, environmental conditions, and landscape similar to that within the park. The article concluded that "up to 45% of sites previously effected by landslides and erosion expressed significant improvement, with soil and plant content residing" (*Effective plantings of low-density manuka as an erosion mitigation, 2020).* Suggesting that "Manuka planted with densities <1100 ha-1 stems are unlikely to provide effective erosion mitigation on steep land until significant root mass develops below the depth of shear plane at which landslides occur *(Effective plantings of low-density manuka as an erosion mitigation, 2020)".* Concluding evidence that Manuka planting is to be utilised as a mitigation method in areas with steep topography or landslide susceptibility, the Manuka must have stems of >1100 ha-1.

Land Management Recommendations

Short Term Recommendations

A short-term land management recommendation in Mt Vernon Park is stock rotation. The "Wet Slopes" on the north-eastern slopes of Mt. Vernon Park are particularly vulnerable to increased soil saturation (See Figure 17 & 18) (Hampton et al., 2018). Since this can increase soil moisture content, erosion risk increases when stock graze on these wetter slopes (Satchell, 2018). Loess soil becomes highly dispersive when wet, rendering them susceptible to shallow-seated landslides and tunnel gully erosion (Christchurch City Council, 2003). Therefore, it is advisable a grazer implements a stock rotation plan, relocating sheep away from over-saturated soils in Mt Vernon Park, especially during wetter periods like winter (Satchell, 2018). During wetter ground conditions stock should be confined to blocks on the drier, southwest-facing slopes in Mt Vernon Park. These blocks are highlighted in blue on the southwest side of the fence line running up the middle of Mount Vernon (Figure 21).

Medium Term Recommendations

The next land management recommendation is concentrating sheep grazing to flatter areas, especially around the main ridgeline's upper and middle sections (See Figure 2**)**. The suggested slope angles in these areas are between 20-28 degrees in the upper back section, 13-20 degrees in the shoulder area, and 3-13 degrees for the summit (See Figure 2). To achieve this, a land management plan has been developed, outlining new proposed blocks within the park by connecting new fence lines to existing ones.

Stage 1

Stage 1 occurs in the medium-term management plan, which involves creating two new blocks using two short fence lines (Figure 22). These areas are highlighted as orange and should be retired from grazing (Figure 21). These retired areas should be utilized for native regenerative planting to help stabilize soil on the steeper slopes (NZ Landcare Trust, 2019). The retired block sizes are 6.12 ha and 3.65 ha. Creating these two new blocks will require approximately 197 m of fencing. Refer to Appendix A & B to help visualise these new fence lines.

Long Term Recommendations

Stage 2

Long term recommendations begin with stage 2 for implementing new fence lines (Figure 22). Stage 2 involves fencing off the steep northeast and southwest slopes, marked in red, which are susceptible to significant tunnel gully erosion (Figure 21). The size of each retired block in stage 2 totals to 64 ha. Refer to Appendix A & B to help visualise these new fence lines.

Stage 3

The final phase involves retiring the upper block at the summit of Mt. Vernon Park, a culturally significant area for Te Hapu o Ngāti Wheke. This area is prone to tunnel gully erosion and mass movement erosion scarp, depicted in purple (Figure 21). This area will not require additional fencing as it is already fenced off. This block is 24.8 ha.

The paddocks highlighted in blue are the most suitable grazing zones, where stock should be kept to reduce erosion after all other blocks are retired (Figure 21). These new grazing blocks create a farming area of approximately 148 ha.

Although the maintenance of drainage culverts located on the lower northeast slopes of the farm track (See Figure 9) can be considered a short-term recommendation, doing this in the long term will help ensure proper water drainage and reduce surface runoff erosion over the future (Department of Conservation, 2008).

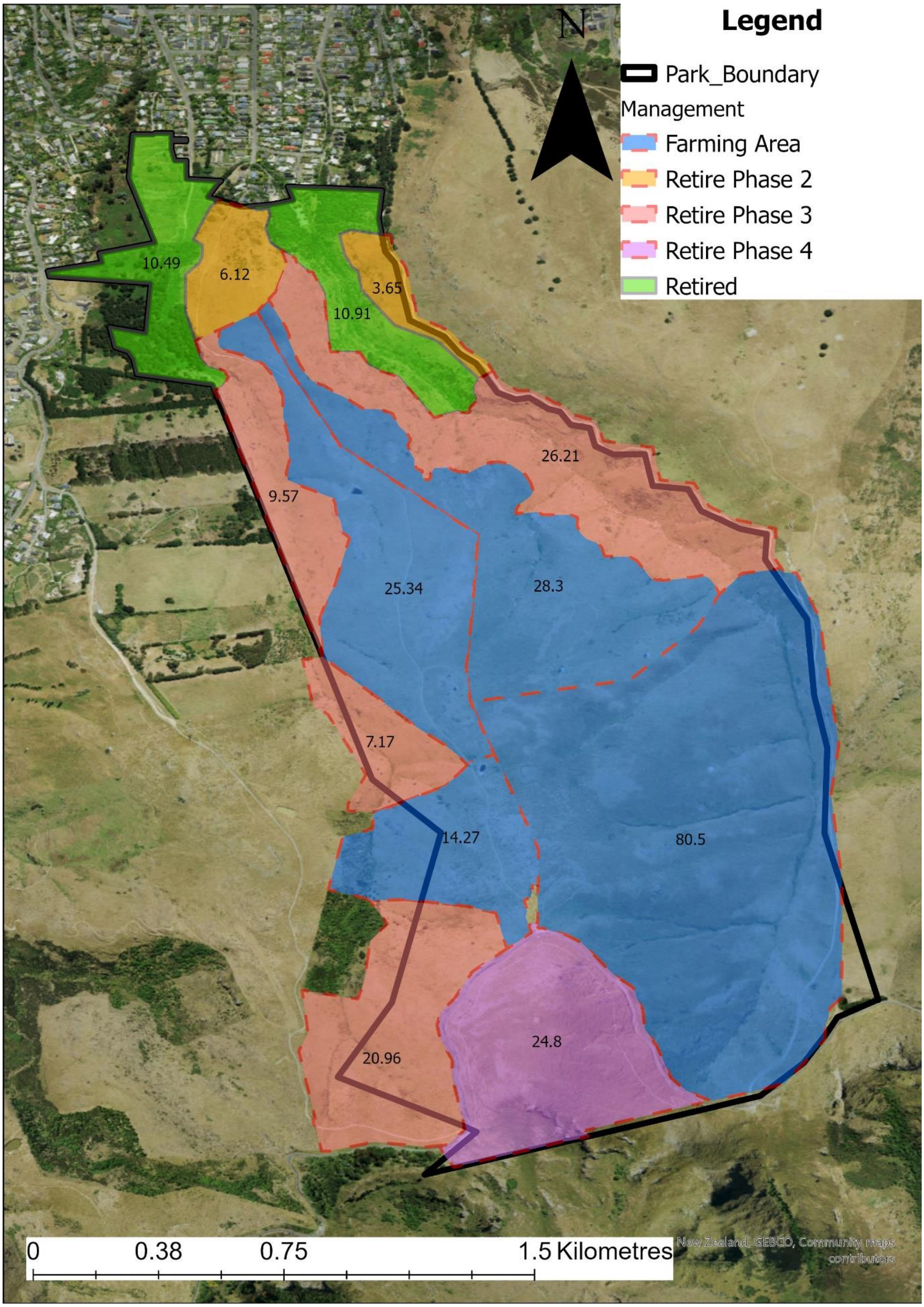


Figure 21: Proposed management blocks for future park management, providing suggestions on areas to retire. Each block's area is presented on the map in hectares.

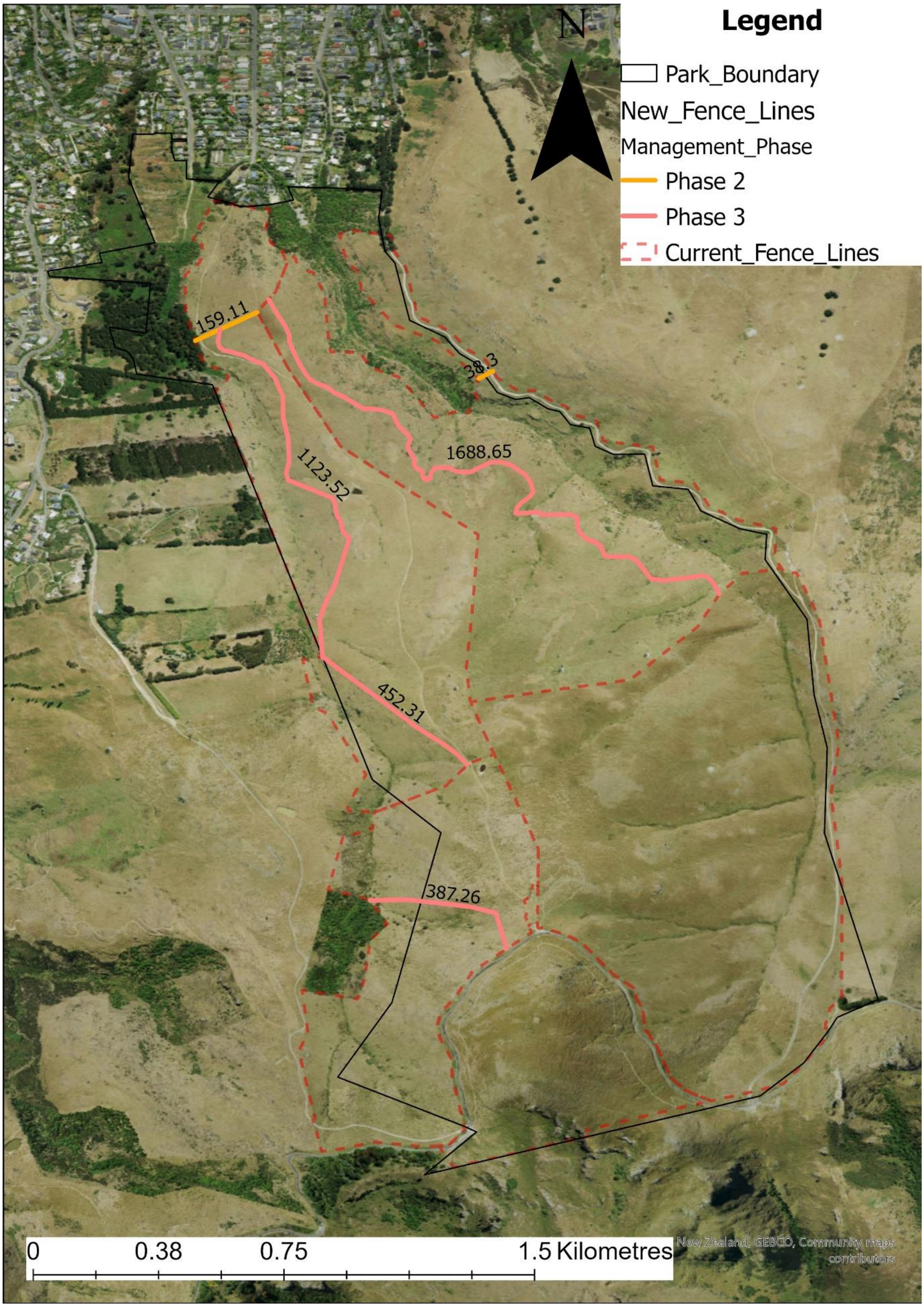


Figure 22: Map showing the new fence lines required for retirement of susceptible land. The length required for each fence line is shown on the map in metres.

Considerations

Implementing land management strategies in Mt. Vernon Park, such as land retirement and revegetation, involves expenses for fencing (estimated at $16.50 per meter for steep hill country land), planting, and maintenance (Ministry for Primary Industries, 2016). Table 1 shows the estimated costs for new fencing across each stage in Mt Vernon Park. Volunteer participation is a cost-effective way to address these expenses. Collaborations with local organizations or securing funding from the Christchurch City Council are also possible. Since land retirement can reduce sediment in waterways, the local council may benefit from funding land management projects in Mt Vernon Park. Given the fire-prone Port Hills location, selecting fire-resistant plant species is vital for revegetation.

Table 1: New fencing costs

Stage 1 Fencing	198 m x $16.5 = $3,267
Stage 2 Fencing	3652 m x $16.5 = $60,258
Stage 3 Fencing	Fencing not required
Total cost for all stages of new fencing	= $63,525

Table 2: Mitigation and Remediation Strategies Method Table for Mt Vernon Park

Method	Stability Duration	Cost	Effectiveness	Application Time
Mulch Mitigation	Short-term	NZD $45,000/ acre	Less Effective	2 hours/ acre
Gravel Mitigation	Short-term	NZD $1,000/ acre	Less Effective	1 hour/ acre
Barrier Stabilization/ Corrosion Inhibitors	Short-term	NZD $100/ square Meter	Less Effective	30mins -1 hour/ meter
Bacterial Culture Mitigation	Long-term Mitigation/ Continuous	NZD $2,887/ acre	Effective	4 hours/ acre and > year stabilization guarantee
Acrylic Polymer and Vinyl Acetate Mitigation	Long-term	NZD $1287/ acre	Effective	1-3 hours / acre
Soil Cementation	Long-term	NZD $48,000/ acre	Effective	4-6 hours/ acre
Vegetation/ Contour Planting Mitigation	Long-term	NZD $1000/ acre	Effective	3 hours/ acre

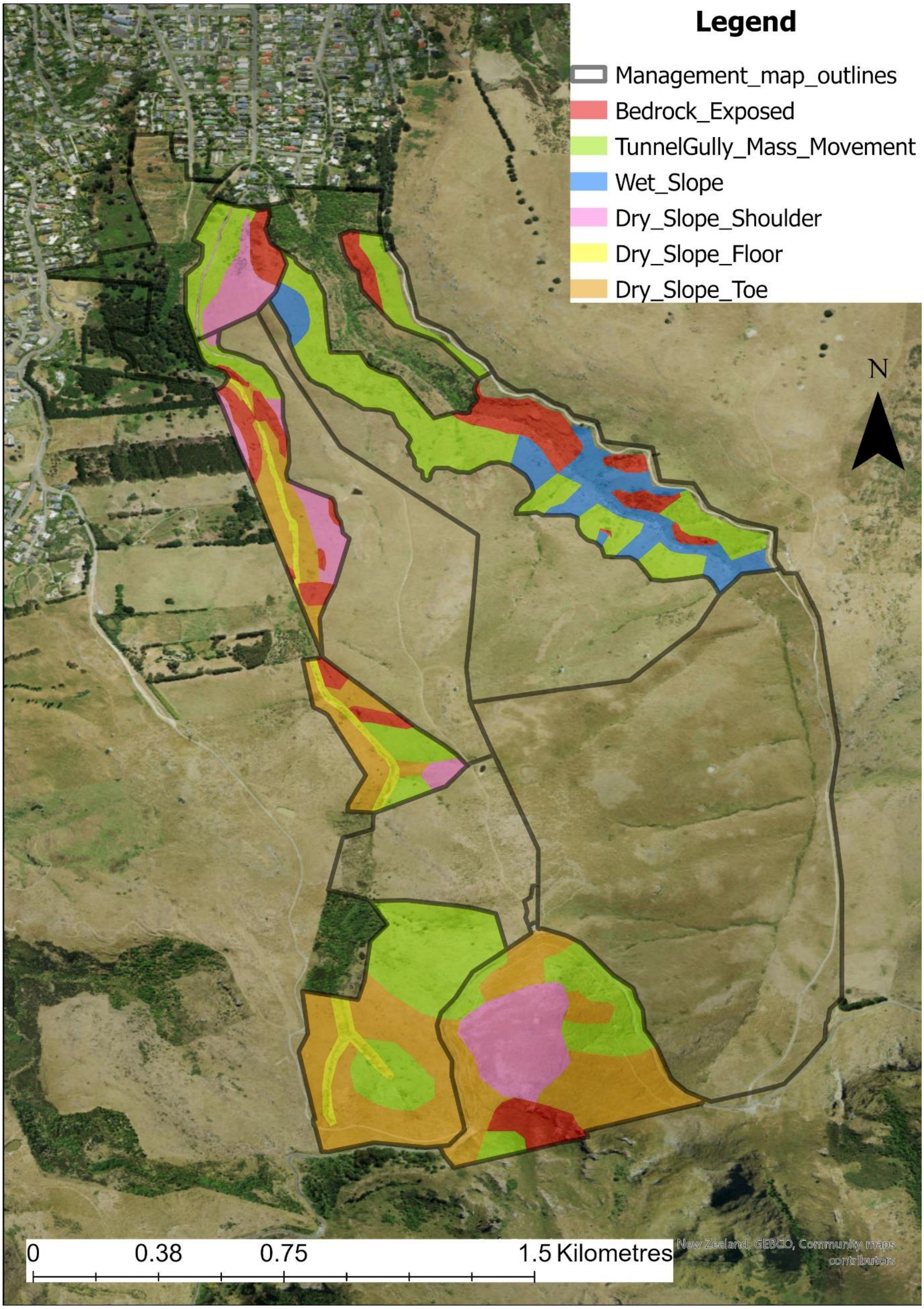


Figure 22: Planting area guide for future retirement blocks within the Park, based on erosional processes.

Area Specific Mitigation

Focusing on areas within the park to adhere long term and short-term mitigation methods. The park's most erosion susceptible and vulnerable areas occur on hillslope landscapes (Shown as 'Back Slope' areas in Figure 15: Ridge cross-section showcasing relationships between landforms, slopes, Regolith types and erosion within the Sumner area and figure 22). Alongside 'Wet' and 'dry' slope areas within the geomorphology of the park's landscape (Shown as 'Wet and Dry Slope' areas in Figure 17 : Lower Park Cross-Section Showing Relationships Between Landforms, Slope, And Erosion, with Inferred Subsurface Geology at Mt. Vernon Park). These areas are of high priority for mitigation and remediation. The ideal short term mitigation method of Barrier stabilisation in association with corrosion inhibitors can be applied to land areas and sections of the park that are without stock grazing, and prior to rainfall for the most successful application. These areas can be identified in Appendix C, Highlighted in blue, in fenced sections without stock.

The barrier stabilisation method is most appropriately applied to the 'Dry slope' areas of these sections to increase stabilisation. Areas within dry slope and back slope regions (geomorphological maps in Figures, 15, 16, 17 and 22) vegetation growth, park trails (high trafficked areas) and hillslope landscapes. Post corrosion inhibitor testing, the correct barrier method can be applied to vulnerable and erosion susceptible areas to increase stability and reduce slips. Post application of this method, the land section for which mitigation has been applied must be sectioned or taped off from stock and foot traffic to ensure a successful application of mitigation for a minimal time period.

Cost effective, ecosystem improving and long-term mitigation to the park, can be applied with vegetation mitigation or contour planting. To create a successful long term mitigation outcome, Kanuka/ manuka planting can be applied to vulnerable erosion areas with stock present, with Manuka stems of >1100 ha-1, and a 20 metre buffer spacing to existing trails to avoid fire risks. (See Appendix D and figure 22). Flax and Tussock planting can be applied to areas of both retired land and grazing land (Figure 21), the plantings may need to be reinforced with barrier stabilisation to avoid contact from sheep within the grazing sections of the Park and further erosion upon planting application.

Conclusion/Summary

In conclusion, this report, which examines erosion susceptibility at Mt. Vernon Park, applies a research approach guided by the following question: "What are areas that are susceptible to erosion at Mt Vernon? And how can the risk of future erosion be reduced and mitigated?" This analysis incorporates historical examination, geomorphological assessments, and landscape mapping to identify areas prone to erosion and potential mitigation options. Furthermore, land use management and mitigation methods were researched and studied to create an area-specific mitigation plan, alongside a land use management.

These plans can be utilised by the Port Hills Park Trust to reduce and mitigate erosion and erosion susceptibility. Mitigation and land use management methods such as corrosion inhibitor barrier stabilisation, vegetation, and contour planting, grazing management, implicating further fencing systems and areas of land to retire. These methods, applied to specific sections and areas within the park will mitigate and reduce further erosion, continuing to maintain and upkeep the landscape of the park for recreational, grazing, and historical activities and practices.

Table 3: Summary of land management recommendations

Short-term recommendation (months - 2 Year)	• Stock rotation strategy
Medium-term recommendation (2-5 years)	• Concentrate sheep grazing in flatter areas around the main ridgeline • Initial land retirement of lower valley sections requiring short fence lines (Stage 1 in land management plan) • Revegetation strategies.
Long-term recommendation (5-10 years)	• Land retirement of middle and upper blocks in erosion prone areas (Stage 2 and 3) • Maintenance of drainage culverts located on the lower northeast slopes of the farm track

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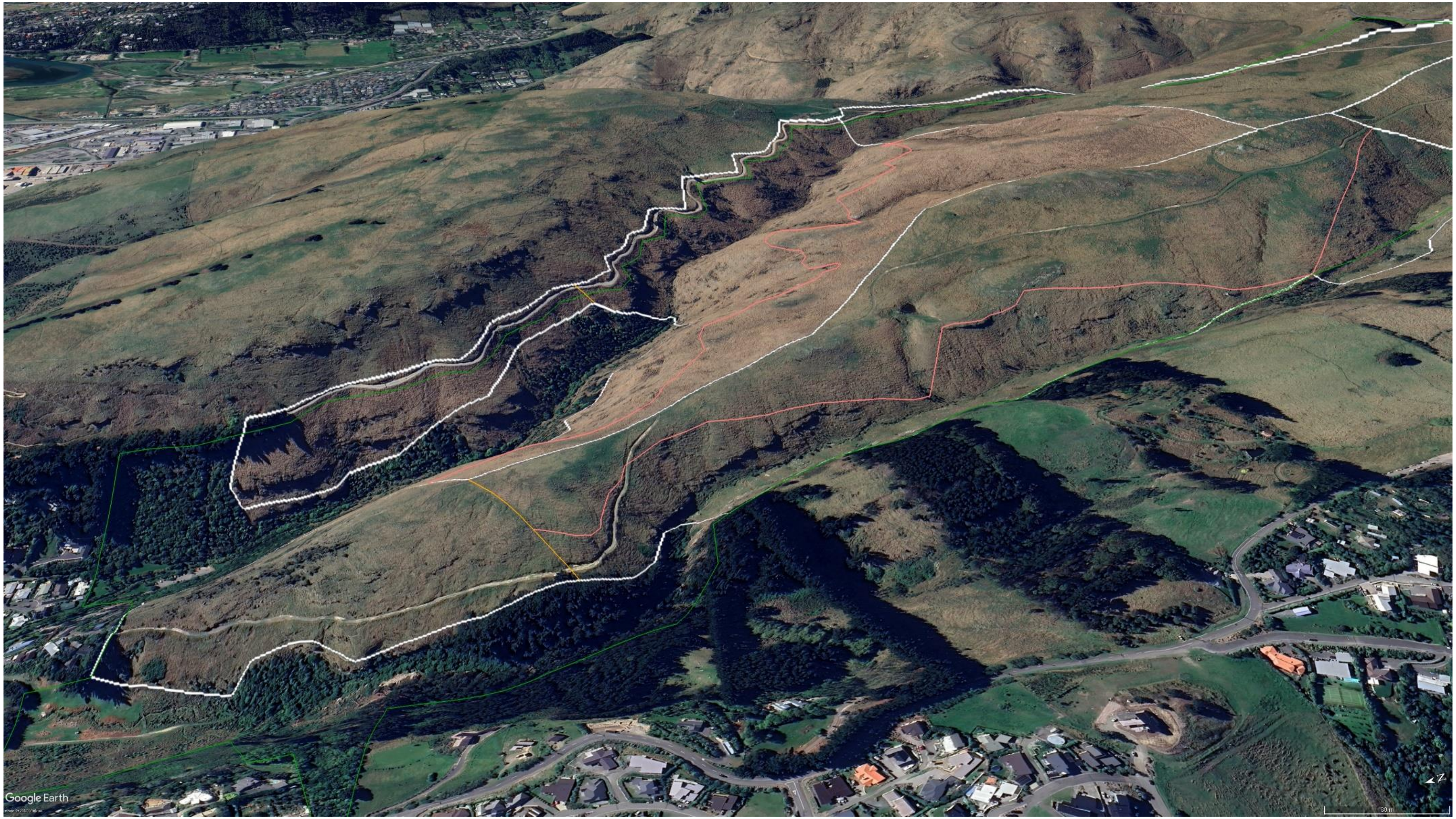
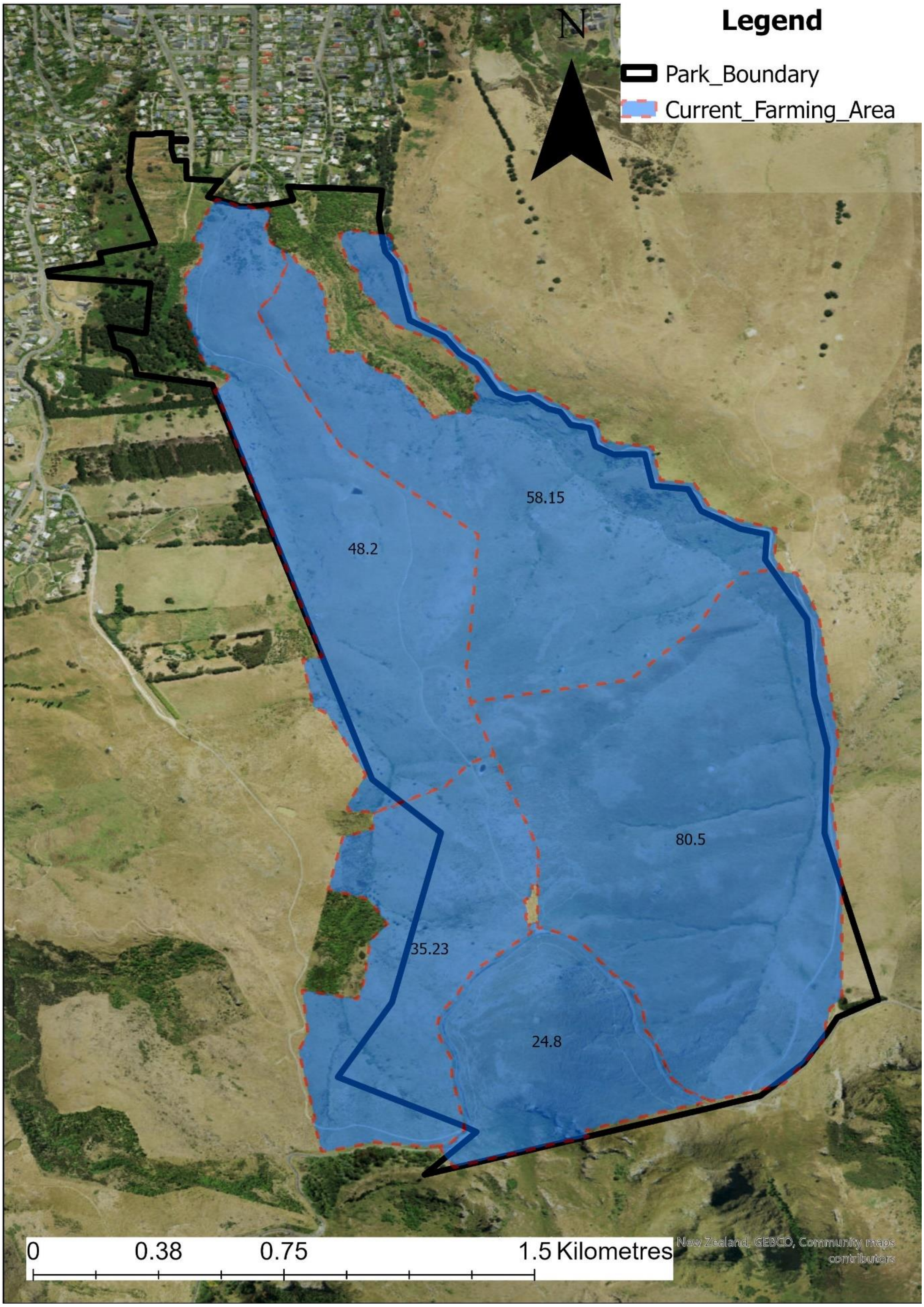
Appendix

Appendix A: Google earth image of Mt Vernon Park showing existing fence lines (white), phase 2 fence lines (orange), and phase 3 fence lines (red).



Appendix B: Google earth image of Mt Vernon Park showing existing fence lines (white), phase 2 fence lines (orange), and phase 3 fence lines (red).



Appendix C: Farm Map showing the current farming blocks within Mt Vernon Park and their respective area size in hectares.

Appendix D: Native plants suitable for restoration planting within the Park (from Colin Meurk, ecologist, Manaaki Whenua Landcare Research , 2020)

SPECIES NAME	**COMMON NAME**	**Dry Slope Valley Shoulder**	**Dry Slope Valley Toe**	**Dry Slope Valley Floor**	**Wet Slope**	**Exposed Bed-rock**	**Tunnel Gully Mass Movement**
		shallow soil	**deep soil**	**deep soil Stage 3**	**Deep soil - Stage 2-3**	**deep cracks**	**seepages**
Alectryon excelsus	titoki				x		
Aristotelia serrata	makomako				x		
Astelia fragrans	bush lily, kakaha				x		
Blechnum penna-marina	little kiokio			x	x		
Brachyglottis sciadophila	shrub daisy					x	
Calystegia tuguriorum	NZ bindweed		edge			edge	
Carmichaelia australis	NZ broom, makaka	x				x	
Carpodetus serratus	putaputaweta				x		
Cassinia/Ozothamnus leptophylla	tauhinu	x				x	x
Clematis afoliata	leafless clematis	x				x	
Clematis foetidissima	stinking clematis		x				
Coprosma crassifolia	thick-leaved mikimiki	x				x	

Coprosma dumosa							x
Coprosma linariifolia	yellowwood			x	x		
Coprosma lucida	shining karamu				x		
Coprosma propinqua	mikimiki	x				x	x
Coprosma rhamnoides	variable coprosma			x	x		
Coprosma rubra	mikimiki				x		
Coprosma virescens	mikimiki	x				x	
Coprosma wallii	mikimiki					x	
Cordyline australis	ti kouka		x				x
Corokia cotoneaster	korokio	x				x	
Cortaderia richardii	toetoe						x
Cyathodes juniperina	mingimingi			x	x		
Dianella nigra	turutu/blueberry			x	x		
Discaria toumatou	matagouri	x				x	
Elaeocarpus dentatus	hinau				x		
Hebe strictissima	Banks Peninsula koromiko		x			x	
Hedycarya arborea	pigeonwood				x		
Helichrysum aggregatum	niniao			x	x		
Hoheria angustifolia	narrowleaved houhere		x	x	x		
Ileostylus micranthus	common mistletoe						

Kunzea ericoides	kanuka		x				
Leucopogon fasciculatus	mingimingi				x		
Libertia ixioides	mikoikoi			x	x		
Lophomyrtus obcordata	rohutu				x		
Macropiper excelsum	kawakawa				x		
Melicope simplex	poataniwha		x	x	x		
Melicytus alpinus	porcupine shrub	x				x	
Melicytus ramiflorus	mahoe			x	x		
Microlaena stipoides	rice grass			x	x		
Myoporum laetum	ngaio		x				
Myrsine australis	mapou			x			
Myrsine divaricata	weeping mapou						x
Olearia fragrantissima	fragrant olearia		x				
Olearia paniculata	golden akeake		x				
Parsonsia capsularis	NZ jasmine			x	x		
Parsonsia heterophylla	NZ jasmine			x	x	x	
Pellaea rotundifolia	button fern			x	x		
Pennantia corymbosa	kaikomako		x	x	x		
Phormium tenax	harakeke						x

Phymatosorus pustulatus	hounds tongue fern			x	x		
Pittosporum anomalum			x			x	
Pittosporum eugenioides	tarata		x				
Pittopsorum tenuifolium	kohuhu		x				
Podocarpus totara	totara		x	x	x		
Prumnopitys taxifolia	matai		x	x	x		
Pseudopanax arboreus	fivefinger		x				
Pseudopanax crassifolius	lancewood/horoeka		x		x		
Pseudopanax ferox	fierce lancewood	x				x	
Rubus schmidelioides	taramoa			x	x		
Rubus squarrosus	leafless bush lawyer	x				x	
Solanum aviculare	poroporo		x				
Solanum laciniatum	poroporo		x				
Sophora microphylla	kowhai		x				
Sophora prostrata	prostrate kowhai	x				x	

Teucridium parvifolium	NZ shrub verbena						
Uncinia sp.	hooked sedge			x	x		
Urtica incisa	dwarf nettle			x	x		