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Soil stability in the Waikato region, 2007-2017

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Table of Contents

Figures

Tables

Executive summary

The Waikato Regional Council (WRC) has conducted four region-wide soil stability surveys (2002[1], 2007[2], 2012[3], and 2017) to establish, and track changes in the state of soil stability and disturbance attributes across a range of land-uses in the Waikato region. This report presents findings from the most recent survey (conducted during November/December 2020 using 2017 aerial imagery) in conjunction with changes in measured attributes over the previous 5 and 10-year monitoring periods. Data from the 2017 survey were collected from 6,155 points, with each point being positioned on a 2 x 2 km grid intersection and 1 ha square centred on each survey point. Data collection and processing were carried out in relation to standard methodologies and procedures developed by the National Land Monitoring Forum (LMF)[4]. In addition to assessing the current state of soil stability and disturbance in the Waikato region using current (2017) imagery, temporal changes in key erosion attributes were assessed over the previous 5 (2007 – 2012) and 10-year (2007 – 2017) survey periods.

At the time of the 2017 survey, 49% of the region's 6,155 surveyed points were classified as stable (showing no evidence of present or past erosion), 26% were unstable and erosion prone (currently inactive but had evidence of past erosion), and 17% contained eroded or eroding surfaces. The remaining 8% of points contained urban areas, rural buildings, and coastal features. Over the 10-year period from 2007 to 2017, the proportion of stable surfaces decreased from 51.8% in 2007 to 49.7% in 2017 ($P<0.05$), and the proportion of erosion prone surfaces increased significantly ($P<0.05$) from 23.5% in 2007 to 25.5% in 2017. Over the same 10-year period, the proportion of eroded surfaces decreased significantly ($p < 0.05$) from 9.6% to 7.5%, while eroding surfaces increased significantly from 7.7% to 9.5%. The increase in actively eroding land may be a result of several damaging storm events that occurred in the Waikato region between 2007 and 2012.

An analysis of soil disturbance data found that 21.2% of the region's surveyed points had some form of land-use disturbance (e.g. cultivated soils, farm tracks, and grazing disturbance), while 9.7% of the surveyed points contained natural erosion (e.g. landslides and gully erosion). In assessing the area of bare soil by disturbance type, farm and forestry tracks contributed most to total land-use disturbance (0.95% of the sampled area), followed by cultivation (0.23%), sealed roads (0.08%), and harvested forest (0.06%). In terms of erosion caused by natural processes, surface erosion (sheetwash and rockfall / exposure of bare rock) caused the most disturbance (0.31% of the sampled area), followed by gully erosion processes (0.08%), slope failures (0.06%), and riparian erosion / deposition (0.05%). When considering change over time, the average area of exposed soil across sample points resulting from land-use disturbance decreased significantly from 9.1% in 2007 to 6.7% in 2017 ($P<0.05$) due to significant decreases in disturbance by cultivation, earthworks, grazing, and forest harvesting. With respect to natural disturbance, the mean coverage of bare soil across sample points increased from 5.9% in 2007 to 6.4% in 2017 ($P<0.05$). Much of the increase in bare soil by natural erosion can be attributed to increases in rockfall/bare rock. However, more long-term data is required to determine if the increase in bare soil by natural disturbance is indicative of a long-term trend or whether the change is due to improved detection of bare rock associated with improved resolution of aerial imagery.

[1] Hicks DL 2003. Soil intactness assessment of the Waikato Region 2002. Environment Waikato Technical Report 2003/14. Hamilton, NZ, Waikato Regional Council.

[2] Thompson AB, Hicks DL 2009a. Soil stability in the Waikato Region 2007. Environment Waikato Technical Report 2009/24. Hamilton, NZ, Waikato Regional Council.

[3] Taylor A 2016. Soil stability in the Waikato Region 2012. Waikato Regional Council Technical Report 2016/20. Hamilton, NZ, Waikato Regional Council.

[4] Burton AS, Taylor A, Hicks DL 2009. Assessing soil stability. Chapter 4 in: Land and soil monitoring: a guide for SoE and regional council reporting. Hamilton, NZ, Land Management Forum.

Assessment of soil stability across the 8 Waikato Catchment Management zones (CMZs) suggested that the West Coast had the highest percentage of surveyed points that were classified as 'unstable' (69% of points within the CMZ), followed by the Coromandel (57%), Lake Taupō (55%), and lower Waikato (45%) CMZs. Farm and forestry tracks contributed most (51-78%) to land-use disturbances across respective CMZs. Cultivation was the next most common land-use disturbance type across CMZs and was most prevalent in the Waipā (0.09% of the regions sampled area), Lower Waikato (0.07%), Upper Waikato (0.03%) and West Coast (0.01%). Disturbance by forest harvesting was most widespread in the Upper Waikato (0.023% of the regions sampled area), Lake Taupō (0.014%) and Waihou Piako CMZs (0.011%).

Natural disturbance was most widespread in the Lake Taupō and West Coast CMZs, with exposure of bare soil equating to 0.31% and 0.14% of the regions sampled area, respectively. The Lake Taupō CMZ, in particular, had high rates of natural disturbance, contributing to 51% of natural disturbance across the region and can be attributed to the highly erodible slopes along the eastern Kaimanawa Ranges and Central Volcanic Plateau. The West Coast CMZ had the highest incidence of disturbance by landslides (0.02% of the sampled area) and open gully erosion (0.02% of the sampled area) reflecting the high erosion risk across the zone due to soft-rock geology and steep slope classes.

When comparing land-use types across the region, there were considerable differences with respect to soil stability and disturbance. Drystock pasture had the highest proportion of points that were classified as 'unstable' (14.7% of the region's sample points), followed by natural forest (8.6%), natural scrub (6.3%), and dairy pasture (5%). The high proportion of 'unstable drystock' land is not surprising given the large number of points located on steep, erodible hill-country. In terms of disturbance, dairy and drystock farms had the highest coverage of exposed soil (0.78% and 0.46% of the total sampled area, respectively). However, the relative contribution of land-use verses natural disturbance differed between dairy and drystock systems. Overall, 95% of the bare soil on dairy farms was due to land-use disturbance compared to 60% for drystock farms, with the remaining 40% being due to natural disturbance processes. Farm tracks caused most disturbance across the region, contributing to 77% of the total bare soil exposure on dairy farms and 37% on drystock farms. The high proportion of disturbance by tracks reiterates the importance of correctly managing tracks/laneways across multiple land-uses. Forestry plantations had the third highest coverage of bare soil (0.18% of the sampled area), most of which was due to forest tracks (56% of forestry disturbance) and harvesting (28%). When assessing changes over time, disturbance due to cultivation on horticulture/cropping land decreased significantly between 2007 and 2017 and is most likely a result of differences in image acquisition dates and resulting differences in the capture of freshly cultivated land. In addition, there was a statistically significant reduction in bare soil by land-use disturbance on drystock pasture and forestry plantations between 2007 and 2017 ($P<0.05$).

Assessment of the current survey design suggests that measured variables (e.g. the percentage of stable vs. unstable points and coverage of bare soil) provide a good estimate of soil erosion across the region as a whole and for domains of interest such as catchment management zone and land-use. It is recommended that the current survey design and statistical analyses are maintained for future surveys to ensure consistency in the collection of specific soil stability/disturbance attributes and to ensure temporal changes are measurable. The recently developed R coding platform is the preferred method for aggregation and analysis of attributes due to the robustness, efficiency, and transparency of the code. It is envisioned that the newly developed R code will be utilised for future surveys to ensure consistency in the reporting approach and enable additional analyses as the size of the dataset increases over time.

1 Introduction

Soil erosion is a naturally occurring process in New Zealand's young and geologically active landscape and erosion rates can be greatly accelerated through removal of vegetation or through poor land management practices (Burton, 2018; Burton et al., 2009). High erosion rates can deplete the productive capability of soil, increase the instability of surrounding land surfaces, damage infrastructure and degrade terrestrial, aquatic and marine ecosystems (Burton, 2018; Taylor, 2016).

Assessing soil erosion at the regional scale is an important component of the Waikato Regional Council's (WRC) statutory obligation under the Resource Management Act (RMA, 1991) to monitor and report on the state of the region's natural resources. The Land Monitoring Forum (LMF), a regional sector special interest group, has developed standard methodologies and protocols for assessing soil stability and disturbance to ensure consistency in the monitoring approach used by regional councils (Burton et al., 2009). The LMF manual for assessing soil stability and disturbance provides a standard procedure, with clear descriptions of the components that are reported as indicators and how to measure them, while allowing councils sufficient flexibility to focus on the components relevant to their regions.

Two key indicators are used to assess the nature and extent of soil erosion at the regional scale, namely, soil stability and soil disturbance. Soil stability provides an assessment of soil's susceptibility to disturbance by natural processes (past and present) and disturbance by land-use (Burton et al., 2009). The assessment of soil stability relates to soil and not to the underlying weathered regolith or rock. Soil disturbance relates to whether a soil is currently at risk of removal through land-use or natural erosion processes and is measured by assessing the area of exposed soil in the sampled area. By assessing soil stability and disturbance across the region using a matrix of points overlying aerial imagery, the state and trend in soil erosion attributes can be estimated for the region.

This report presents data and discusses results from a survey of soil stability and disturbance undertaken for WRC in 2021 using aerial imagery acquired during the summers of 2016/2017, 2017/2018, and 2018/2019. The latest survey is referred to as the 2017 survey because most of the aerial imagery was collected during the summer of 2017. Previous surveys have been undertaken for the Waikato region based on aerial imagery acquired in 2002 (Hicks, 2003), 2007 (Thompson & Hicks, 2011), and 2012 (Taylor, 2016). In addition to previous state reports, a separate 'change' report was produced during each survey year to analyse temporal trends in soil stability and disturbance attributes. Previous 'change' reports include Thompson and Hicks (2009a) and Hicks et al. (2018), both of which included the 2002 survey data (Hicks, 2003). For the current round of reporting, the 2017 soil stability and disturbance results were presented alongside temporal trend data to create an integrated state-and-trend report. Data collected from the 2002 survey was excluded from the temporal analyses due to key changes in the methodology that took place between the 2002 and 2007 surveys (Thompson & Hicks, 2009b).

The aims of this report are to:

- describe the state of key soil stability and disturbance attributes across the Waikato region by analysing 6,155 survey points overlaying the most up to date (2017) aerial imagery.
- assess soil stability and disturbance regionally and by catchment management zone;
- evaluate soil stability and disturbance by land-use type to identify links between land-use management and specific erosion types or issues.
- describe changes in soil stability attributes and soil disturbance, including exposure of bare soil, over the previous 5-year and 10-year periods (using 2007, 2012, and 2017 survey data); and
- review the survey design and recommend changes for future surveys if required.

2 Methods and materials

2.1 Survey design

Data was collected from aerial photographs using the point analysis method outlined in the Land Monitoring Forum (LMF) guidelines document for soil intactness surveys (Burton et al., 2009). The LMF guideline document provided a consistent framework for regional councils to gather, interpret, and compare data between regions, while also enabling aggregation of data for national reporting (Thompson, 2021). Several surveys have been undertaken in the Waikato region on aerial photography collected between 2002 and 2017 using the standard methodologies developed by the LMF (Taylor, 2016). Utilising the consistent grid-type sampling methodology over successive sampling periods has enabled WRC to monitor genuine changes in soil stability and disturbance attributes, while minimising error rates.

2.2 Description of survey methods

The Waikato Regional Council (WRC) 2017 survey of soil stability and disturbance followed the standard procedure documented in Burton et al. (2009)

2.2.1 Survey concepts and definitions

A full description of survey definitions and key concepts that underpin the soil stability methodology can be found in the LMF guidelines (Burton et al., 2009). The guideline interprets soil erosion or accumulation using the broader framework of soil stability and disturbance. Definitions of soil stability and soil disturbance are provided below:

Soil stability
Soil stability provides an assessment of the soil's susceptibility to disturbance by natural and land-use-related processes and identifies whether points are on stable or unstable surfaces. Unstable surfaces include erosion prone, recently eroded, or freshly eroded surfaces.

Soil disturbance
Soil disturbance identifies the exposure of bare soil and therefore potential for movement. Where exposure of bare soil was observed, the disturbance type was broadly categorised based on factors contributing to the soil disturbance in the immediate area. Disturbance was attributed to either land-use-related activities (e.g. cultivation, harvest) or natural process (e.g. landslide, slump).

Burton et al. (2009) defines several other terms used throughout this report and a full list of these terms and their definitions are provided in Appendix 1. Important terms relate to erosion susceptibility (e.g. stable or erosion prone), nature and type of disturbance (e.g. land-use-related disturbances), and land-use types (e.g. dairy or drystock).

2.2.2 Monitoring area

The survey area is the area administered by the Waikato Regional Council (WRC), covering about 25,000 square kilometres (Figure 1). A 2 km x 2 km regular matrix of points was distributed across the region on the NZTM map grid, giving a total of 6,155 sample points (Taylor, 2016; Thompson, 2021). At the regional scale, the current sample size provides a balance between achieving acceptable error margins and confidence limits, while minimising the cost/effort of analysis, interpretation, and recording of data (Thompson, 2021). For catchment scale monitoring, higher resolution sampling may be required to increase statistical power to detect smaller changes in soil attributes. As an example, Burton (2018) sampled individual catchments in Hawke's Bay using a 1 km^2 matrix of points and in the Waikato, Thompson and Hicks (2011) sampled the Matahuru Catchment using a sample density of 5 points per km^2.

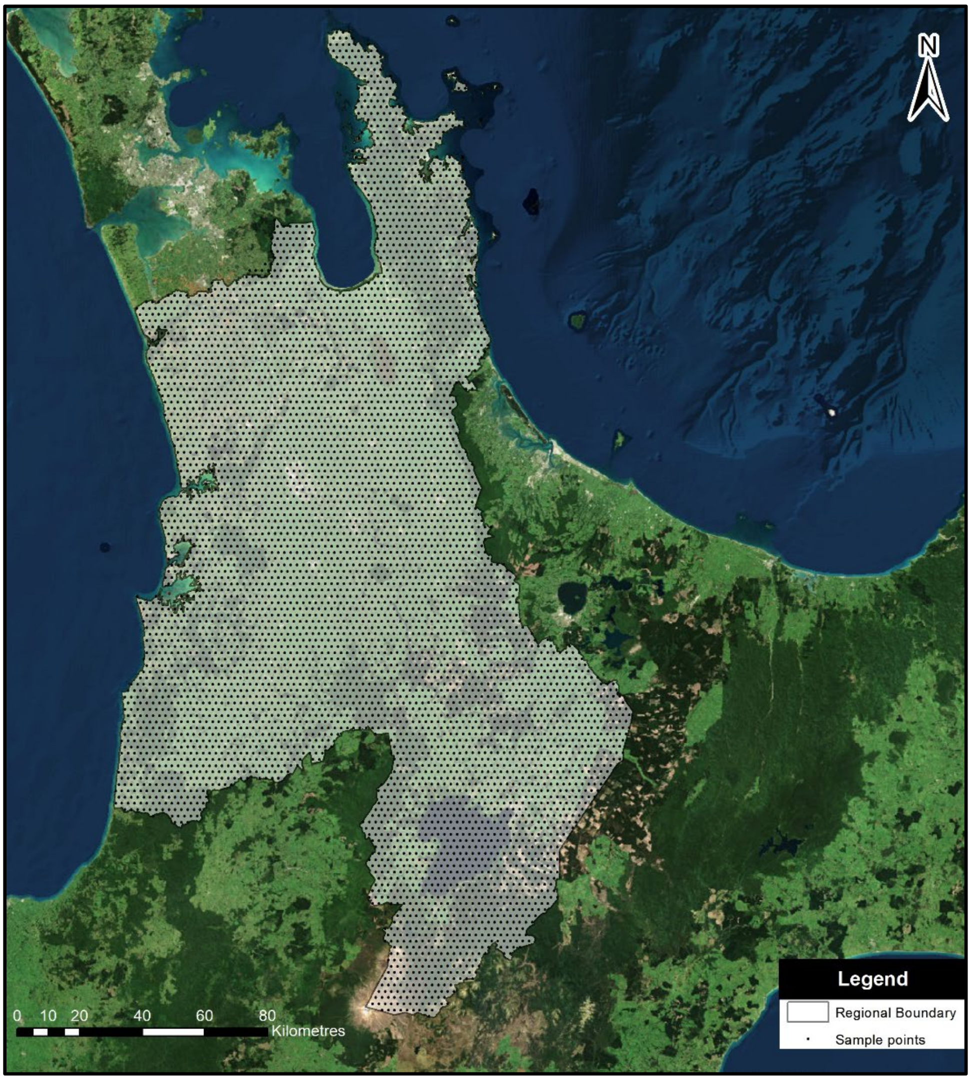


Figure 1: Survey area for the Waikato region soil stability survey in 2021. Note that the imagery used for the 2021 regional survey was based on 2017 imagery.

2.2.3 Sampling procedure

Sample points were overlayed on digital orthorectified aerial images captured over three flying seasons (summer periods) 2016/2017, 2017/2018, and 2018/2019. Each sample point was positioned on the 2 x 2 km grid intersection and the area of observation for recording soil stability and disturbance information was defined by a 1 ha square centred on individual sample points (Figure 2).

Figure 2: A subset of sample points positioned at 2 km intervals on the NZTM map grid. A 1 ha square was centred on each point to provide an observation area for assessing soil disturbance.

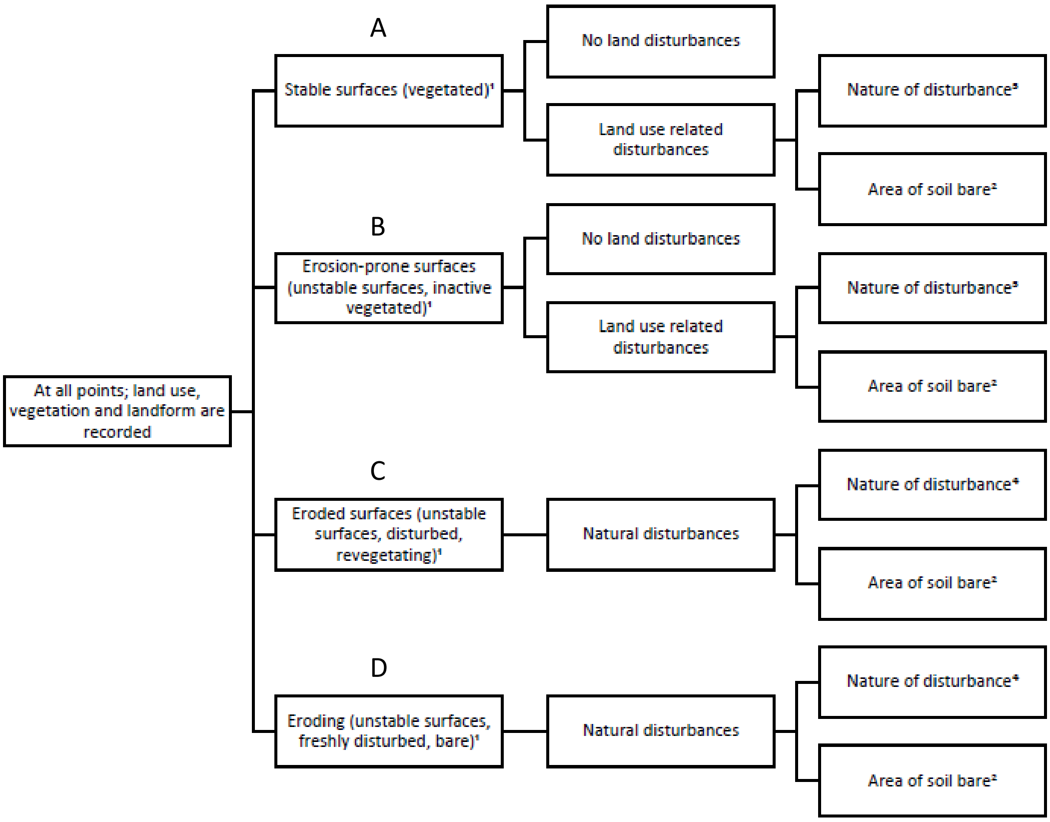
Each sample/grid point was linked to an attribute table in ArcGIS software which contained attribute information from previous surveys and would appear when the user selected an individual point. Using the 2017 imagery, each of the 6,122 points were re-assessed, and amendments were made to the attribute table where necessary. When the interpreter was satisfied that the information associated with a selected point was correct, the 'checked' code was changed from '0' to '1', thereby indicating that the point had been assessed. The colour of the 'point' on screen would then change from red to green to enable the user to keep track of which points had been re-assessed (Taylor, 2016; Thompson, 2021). Note that for the 2017 survey, an additional 33 points were assessed, increasing the sample size from 6,122 points to 6,155 points. The additional points were due to a regional boundary change in 2010 when an area of approximately 21,000 ha was transferred from the Auckland region to the Waikato region. The Area included the Hunua Ranges to the western Firth of Thames including Wharekawa and Whakatiwai.

Assessment of points was generally undertaken at a 1:5,000 scale. However, a viewing scale of 1:3,000 was often used for interpreting erosion type and extent. Occasionally, the assessor would zoom in further to a 1:2,000 scale to acquire more detailed information relating to attributes such as erosion type and vegetation type. To gain greater contextual information about surrounding land-use, landform and/or stability, the assessor would also occasionally zoom out to a 1:10,000 scale. The assessment of individual points would take between 30 and 90 seconds depending on the site-specific characteristics and whether changes had occurred since the previous survey (Thompson & Hicks, 2011).

2.2.4 Data recording

The attributes that were recorded during the 2017 survey were identical to those collected in the 2007 and 2012 surveys, and included land-use, secondary vegetation, soil stability, soil disturbance type, landform, and area of freshly disturbed soil. Categories which had not changed since the previous 2012 survey were not re-recorded. Standard codes that were used when recording data can be found in Appendix 1.

Figure 3 outlines the process by which observations were categorised at each sample point in accordance with the standard LMF methodology (Burton et al., 2009). The four categories of land stability (stable, erosion prone, eroded, and eroding) were classified based on evidence of existing and historical erosion at the time of the survey. Disturbance caused by land-use-related activities were only recorded for stable and inactive erosion prone surfaces (A and B, Figure 3), while disturbances due to natural processes were recorded for eroded and eroding surfaces (C and D, Figure 3). Where disturbance due to land-use or natural processes was recorded at a given point, the area of bare soil was calculated using the cluster sampling methodology (see section 2.2.5).



Notes:

[1] The categories give an indication of the number of samples which contain land that are stable, erosion prone, eroded or eroding surfaces.

[2] Using the cluster sampling method the % of bare soil within the one hectare sampling point can be determined.

[3] Nature of disturbance for land use related disturbances include cultivation, grazing, tracking, earthworks, spraying, grazing, etc.

[4]Nature of disturbance from natural processes include gully, landslide or slip, sheet, streambank, etc.

Figure 3: Description and selection methods for the categories used in the point sample method outlined in the LMF guidelines (Burton, 2018).

2.2.5 Cluster sampling for bare soil

In cases where bare soil was observed within the square centred on a sample point, the cluster sampling method was used to calculate the percentage of bare soil within the 1 ha area. A full description of the cluster sampling methodology can be found in the LMF guidelines (Burton et al., 2009) and the methodology report produced by Thompson (2021). In short, a 1 ha square was centred on each of the 6,155 sample points and 100 regular spaced points were placed within the 1 ha area (Figure 4). Where bare soil was observed directly under a point, this was considered as 1% bare soil. Points overlaying bare soil were summed to calculate the total percentage of bare soil within the 1 ha square.

Figure 4: 100 cluster sample points (one at each grid intersect) were placed within a 1 ha square to calculate the percentage of bare soil at each of the 6,155 sample points across the region.

Given the accuracy and quantitative nature of the cluster sampling method (Thompson, 2021), the area of bare soil at individual sampling points were summed to estimate the total area of bare soil within the sampled area of the Waikato region.

2.2.6 Data storage

Sample point locations, one-hectare squares, and cluster measuring grids were stored in ArcMap feature class files and the associated geodatabase. The associated attribute table was exported as an Excel spreadsheet and subsequently imported into R for further analysis. See Norris (2022) for a full description of data management protocols and the associated analysis procedures.

3 Data analysis

3.1 Methods for determining state

In 2016, WRC commissioned a review of the soil stability programme by Scion Ltd. (Kimberley, 2016) to assess the effectiveness of the current approach and whether improvements could be made (Hicks et al., 2018). The report concluded that the WRC methodology for assessing soil stability had been applied correctly and was consistent with methods outlined in the LMF guidelines.

In addition to assessing the current soil stability methodologies, Kimberley (2016) provided recommendations for improving data processing and the application of statistical analyses. As part of the review, a 'master spreadsheet' was developed in Microsoft Excel with customised sorting and statistical functions to collate, analyse, and summarise data more efficiently and accurately (Kimberley, 2016). The 'master spreadsheet' developed by Kimberley (2016) was used by Taylor et al. (2016) for the 2012 regional soil stability survey. To further improve the efficiency and accuracy of the analysis procedure, while also minimising potential errors associated with the 'manual handling' of data, an R script was developed to process and analyse the soil stability data. The rationale behind using the R statistical programme (R Core Team, 2021) for analysis is that an established coding platform is a considerably more robust, efficient, and transparent means of analysing large datasets compared to the traditional filtering/sorting tools available in MS Excel. The R script uses a series of functions to sort data and apply statistical methods to determine the over-all state and trend of soil stability attributes across the Waikato region. For the current round of soil stability analysis (2017), all data processing and statistical analyses were carried out using the newly developed R coding framework (Norris, 2021a).

To ensure that the statistical methods were correctly applied in the newly developed R code (Norris, 2021a), Environmental Statistics Ltd. was commissioned to undertake a review of the latest analysis protocol (Kimberley, 2022). Overall, the report concluded that the statistical methods and associated R-code was being applied correctly. However minor changes were applied to the existing code to improve efficiency of data analysis and a new statistical approach was recommended for assessing changes in bare soil over time (see section 3.2).

3.1.1 Analysis of soil stability at one point in time

Point counts were expressed as a percentage of the sample or subsample being assessed. The analysis largely consisted of estimating the percentage of points within a given category; e.g. the percentage area with stable, erosion prone, eroded, or eroding surfaces (Kimberley, 2016). The precision of these estimates is expressed using 95% confidence intervals obtained using normal approximations for a percentage derived from a binomial variate. The 95% confidence interval for a percentage measurement is calculated using the following equation:

$$95\%CI(P) = 1.96\ X\ \sqrt{P(100-P)/N}$$

Where P is the % of grid points in the subgroup, and N is the total number of points in the survey.

3.1.2 Analysis of bare soil at one point in time

The area of bare soil within a subgroup is expressed as a percentage of the total sampled area within the region and was calculated using the following equation:

$$\%Bare = b\ X\ N_1/N$$

Where b is the % of points with bare soil in the cluster plots within a given subgroup, N_1 is the number of grid points in the subgroup, and N is the total number of grid points.

To estimate the precision of *%Bare*, the standard error of b was calculated using:

$$se(b) = sd/\sqrt{N_1}$$

Where *sd* is the standard deviation of *b.* The next step was to calculate the standard error of *N_1/N* using a similar method to that described above for P:

$$se(\frac{N_1}{N}) = \sqrt{[\frac{N_1}{N}(1 - \frac{N_1}{N})]/N}$$

Because %Bare is a product of b and N_1/N, its standard error was calculated using the standard formula for a standard error of a product. This was converted into a 95% confidence interval using an assumption of normality:

$$95\%CI(\%Bare) = t \times \sqrt{b^2\ se\ (\frac{N_1}{N})^{\ 2} + (\frac{N_1}{N})^{\ 2}\ se\ b^2}$$

Where t is a tabulated t value with N_1-1 degrees of freedom. For large subgroups, t can be approximated by 1.96 (Kimberley, 2016).

3.2 Methods for estimating changes over time

Determining change in the percentage of points

To determine changes in the percentage area within a subgroup using grid point samples, *McNemar's test* was applied using the protocols outlined in Kimberley (2016). Assuming that the number of points in a particular subclass is N_1 at time 1, N_2 and time 2, and that N_{12} points are in this subgroup in both times 1 and 2, then *McNemar's test* is obtained by applying the following equation:

$$M = (N_1 - N_2)^2\ /(N_1 + N_2 - 2 \times N_{12})$$

The calculated statistic M is compared against tabulated chi-squared values with 1 degree of freedom to determine the statistical significance of change over time. Note that *McNemar's test* can only be applied to repeat samples, which in the case of the WRC regional survey equates to 5,878 points. The lower sample number is largely a result of uninterpretable datapoints during the 2007 survey due to missing aerial imagery in some parts of the region. A key recommendation of this report is to reassess the 2007 imagery and increase the 'repeat dataset' to 6,122 points.

Determining change in the coverage of bare soil

For assessing change in bare soil using the cluster point methodology, a non-paired *Wilcoxon signed-rank test* was applied to survey grids that were sampled over successive years. Hence, when undertaking the change analysis, the 5,878 repeat sample sites were processed, and sample means for respective survey years were recalculated for the adjusted sample size. See (Kimberley, 2022) for a full description of statistical methods and (Norris, 2022) for a description of the R code and applied statistical approaches.

3.3 Soil stability

Soil stability is a measure of how well the regions soil is being kept in place as a resource for farming, forestry, and conservation. Soil stability is categorised into four classes to differentiate stable and unstable land and to ascertain the extent and timing of past soil disturbances.

3.3.1 State

In 2017, 49.4% of the surveyed points were classified as stable with no evidence of past natural erosion (Figure 5). Points that were classified as stable were fully vegetated unless the topsoil was disturbed by land-use activities such as cultivation or harvesting. Stable surfaces include protected floodplains, drained wetlands, elevated terraces, rolling down lands, and old coastal dunes with weathered soils (Burton et al., 2009).

Of the regions sample points, 25.9% contained unstable erosion prone surfaces (U) that showed evidence of historic erosion but were inactive at the time of the survey (Figure 5). As with stable surfaces, erosion prone surfaces were fully vegetated at the time of survey unless the topsoil was exposed by land-use activities.

Eroded surfaces (R) occurred on 7.5% of the regions sample points and eroding surfaces (E) were observed at 9.7% of the regions sample points (Figure 5). Eroded surfaces (R) are defined as areas that have recently eroded but are partially vegetated, while eroding (E) surfaces are actively eroding and include areas subject to mass movement (slope failure), river/stream bank erosion, and young coastal dunes. Surfaces classified as "other" made up 7.5% of the surveyed points and included urban areas (1.2%), rural buildings/yards (2.8%), and waterbodies/coastal features (3.5%).

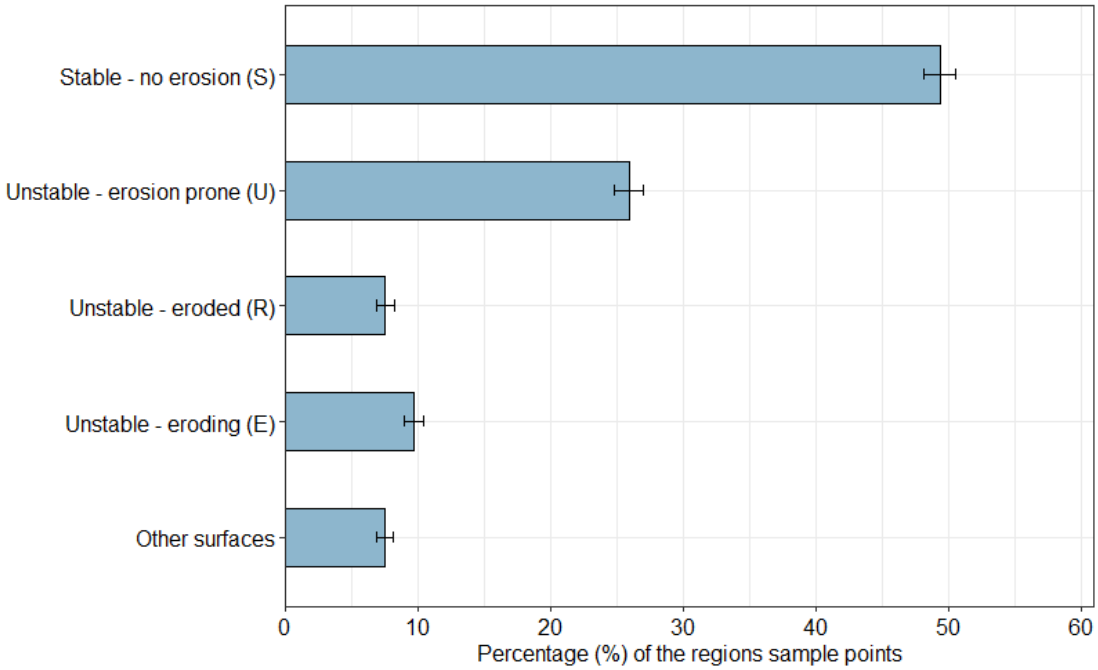


Figure 5: Percentage of sample points that contained stable and unstable surfaces across the Waikato region in 2017. 'Other surfaces' included urban areas, rural buildings/yards and water bodies/coastal features. Error bars represent 95% confidence intervals.

To determine geographical differences in soil stability across the Waikato region, points were aggregated by Catchment Management Zone (CMZ). There are 8 CMZs across the Waikato region and these are identified in Figure 6. The West Coast CMZ had the highest number of points that were identified as unstable, with 69% of the surveyed points being classified as either erosion prone (U), eroded (R), or eroding (E). Both the Coromandel and Taupō CMZs had 55% of the surveyed points that were classified as unstable, while the Waipā and Lower Waikato zones had 43% and 45% of points with unstable land, respectively. The CMZs with the lowest percentage of unstable points were the Waihou-Piako (31%), Upper Waikato (35%), and Central Waikato (18%) zones. Although the point-based soil stability method gives an indication of the relative differences in soil stability between CMZs, the area of stable verses unstable land is not quantified. Nevertheless, spatial differences in soil stability classes and changes over time give an indication of (a) particular land-based issues within respective CMZs (e.g. the proportion of eroding vs. eroded land) and (b) the effectiveness of land/catchment management approaches and their impact on soil stability.

Points classified as ‘e’ in Figure 6 contain surfaces that are actively eroding and show evidence of freshly disturbed soil. The West Coast zone had the highest proportion of points that were classified as ‘actively eroding – e’ (19%) – followed by Lake Taupō (12%), Waipā (12%), Lower Waikato (9%), and the Coromandel (8%). The Upper Waikato, Waihou-Piako, and Central Waikato CMZs had less than 7% of points that showed evidence of active erosion. In terms of risk for future erosion events, the West Coast management zone had the highest risk due to the soft rock geology and steep slope classes. Erosion risk may be further exacerbated by high storm frequency and rainfall intensity, both of which are likely to increase with climate change.

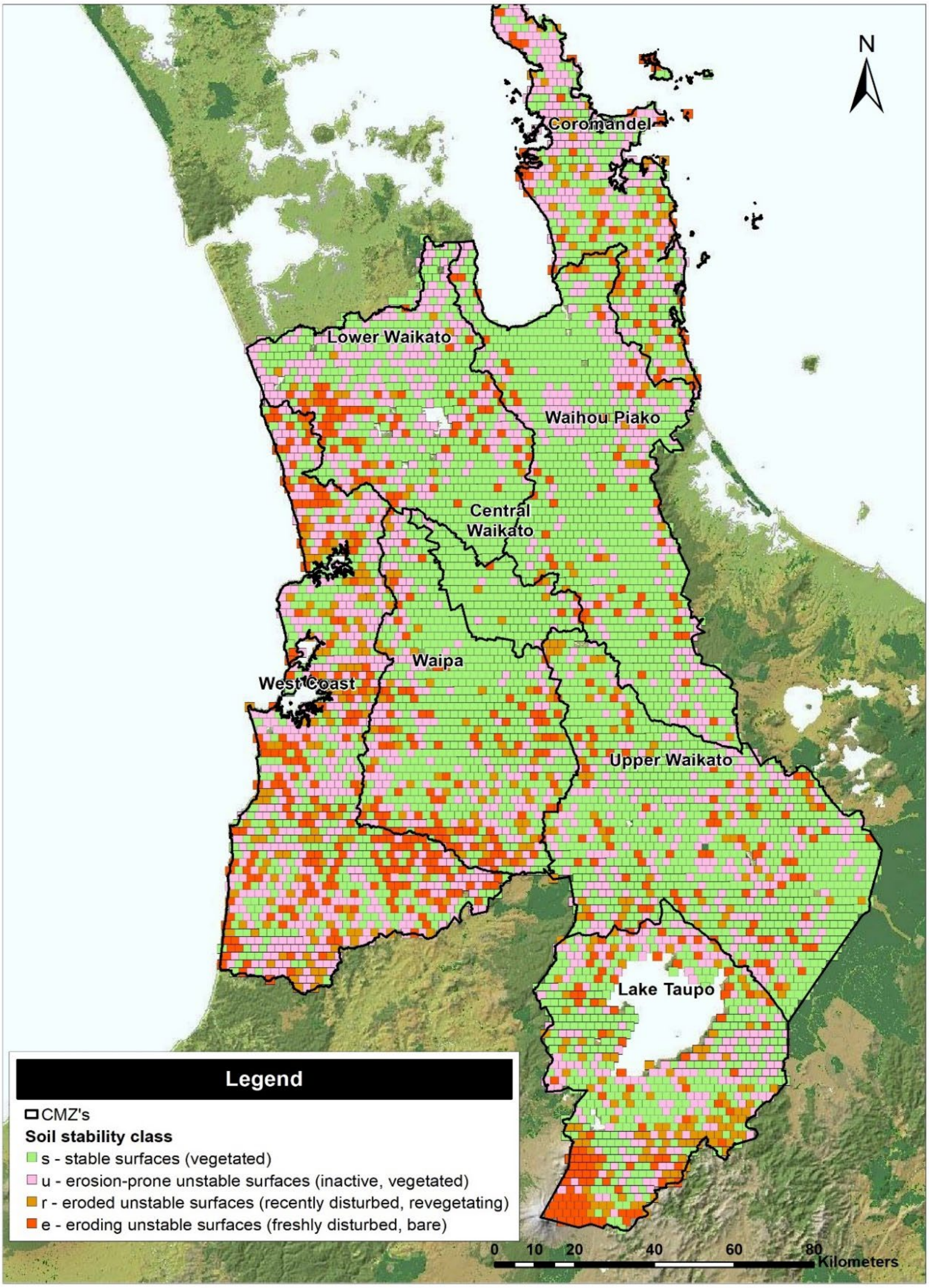


Figure 6: Map showing the location of 'unstable' points (U, R, and E in Figure 5) for respective catchment management zones (CMZs) in the Waikato region.

3.3.2 Changes over time

Over the 10-year period, from 2007 to 2017, there was a statistically significant decrease in the coverage of stable surfaces across the region (Figure 7). The greatest change occurred between 2012 and 2017, with a 2% reduction ($P<0.05$) in the proportion of surfaces that were classified as 'stable'.

For erosion prone (U) surfaces, a statistically significant decrease was observed between 2007 and 2012 (1.5%), followed by a statistically significant increase of 3.5% between 2012 and 2017. Eroded surfaces (R) saw no change between 2007 and 2012, however, a significant decrease of

2.3% occurred between 2012 and 2017. Eroded surfaces are those that have been disturbed in the past decade but have started to stabilise through revegetation.

Eroding surfaces are defined as areas where erosion is active and bare soil is clearly exposed on the land surface. In a previous WRC soil stability report, Hicks et al. (2018) noted that several damaging rainstorms occurred in the Waikato between 2007 and 2012 and may explain the statistically significant increase from 7.7% in 2007 to 9.1% in 2012. However, no changes in the number of actively eroding surfaces were observed between 2012 and 2017.

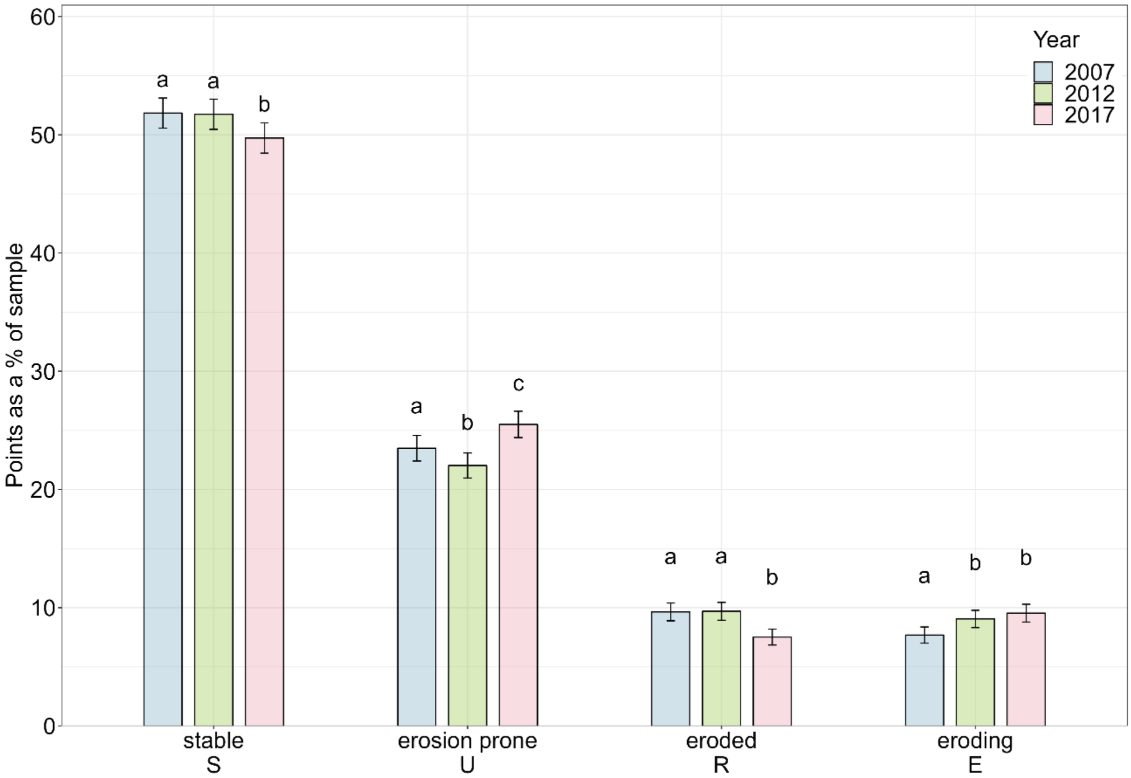


Figure 7: Soil stability across the Waikato region in 2007, 2012, and 2017. Within each category, percentages with different letters represent statistically significant differences (P < 0.05). Source data for this graph can be found in Table A2-3, Appendix 2.

3.3.3 Summary of key soil stability results

2017 results (state)

- 49.4% of the 6,155 surveyed points in the Waikato region were classified as stable.
- 25.9% of the regions surveyed points contained erosion prone points (U) that showed evidence of historic erosion but were inactive at the time of the survey.
- 7.5% of points contained eroded surfaces and 9.7% of points were identified as containing actively eroding surfaces.
- 7.5% of the surveyed points contained urban areas (1.2%), rural buildings/yards (2.8%), and waterbodies and coastal features (3.5%).
- The West Coast catchment management zone (CMZ) contained the highest proportion of actively eroding points (19%), followed by the Lake Taupō (12%), Waipā (12%), Lower Waikato (9%), Coromandel (8%), Upper Waikato (7%), Waihou-Piako (5%) and Central Waikato (4%) CMZs.

Changes in soil stability over time (2007 – 2017)

- Stable surfaces remained unchanged between 2007 and 2012, however a statistically significant decrease of 2% occurred between 2012 and 2017 ($P<0.05$).
- Erosion prone surfaces (i.e. currently stable but show evidence of past erosion) decreased by 1.5% between 2007 and 2012, and increased by 3.5% between the 2012 and 2017. Corresponding to the increase in erosion prone surfaces was a decrease (2.2%) in eroded surfaces (i.e. recently disturbed surfaces that have started to revegetate and stabilise).
- Actively eroding surfaces increased significantly ($P<0.05$) from 7.7% to 9.1% between 2007 and 2012. However, from 2012 to 2017, the number of actively eroding surfaces remained unchanged.

3.4 Soil disturbance

Soil disturbance identifies the exposure of bare soil at the land surface from land-use activities (e.g. cultivation or harvesting) or natural erosion processes (e.g. landslides or gully erosion). Soil disturbance is assessed by examining a 1 ha square centred on each of the region's sample points and identifying (a) the predominant disturbance type within the 1 ha area and (b) calculating the area of bare soil using the cluster point methodology (see section 2.2.5). In the following sections, results are aggregated by land-use activities or natural erosion processes to gain a better understanding of the mechanisms contributing to soil disturbance. As for the previous section, we examine the current state of soil disturbance across the Waikato region (as determined from the 2017 survey) and changes in soil disturbance between 2007 and 2017.

3.4.1 State

Disturbance by land-use-related activities

Land-use activities contributing to soil disturbance were broadly classified into seven groups (roads, tracks, earthworks, drains, harvest, grazing pressure, and cultivation) and definitions for respective disturbance types can be found in Appendix 1. Land-use-related activities resulted in disturbance at 21.2% of the region's sample points and exposure of bare soil across 1.4% of the sampled area (Figure 8). Farm and forest tracks contributed most to overall disturbance, with exposure of bare soil equating to 0.95% of the total sampled area (Figure 8). Moreover, 68% of land-use disturbance in the region was a result of farm or forest tracks and highlights the importance of managing tracked areas carefully to minimise nutrient and contaminant transport from high-risk areas to waterways.

Cultivation was the second most prevalent type of land-use disturbance, with total exposure of bare soil equating to 0.23% of the sampled area and overall contributed to 16% of the bare soil exposed by land-use activities. Forest harvesting resulted in bare soil across 0.06% of the sampled area (4% of land-use disturbance) and grazing disturbance caused bare soil exposure across 0.04% of the sampled area (3% of land-use disturbance). Disturbance resulting from drains and earthworks was negligible, with exposure of bare soil equating to 0.04%. Further information on the impact of land-use on soil disturbance is provided in section 4.3.

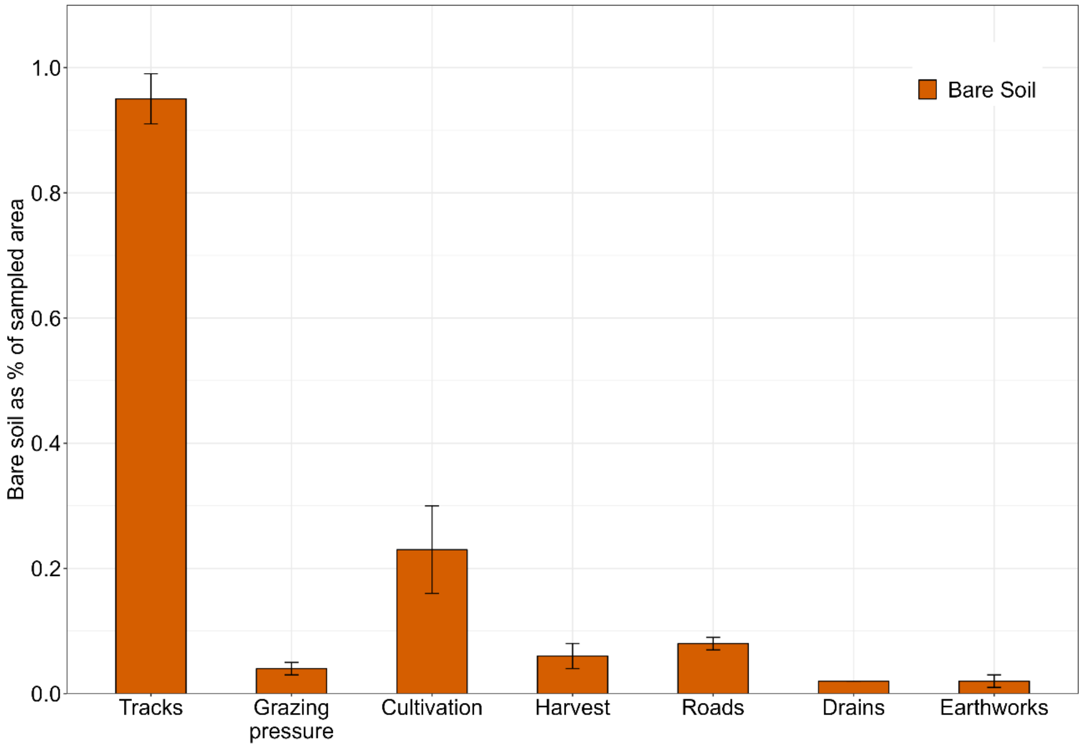


Figure 8: Bare soil resulting from land-use activities expressed as a percentage of the total sampled area (6,155 ha). Error bars represent the 95% confidence intervals.

To identify spatial differences in land-use-induced disturbance across the region, the exposure of bare soil resulting from land-use activities was calculated for each of the eight catchment management zones (CMZs). In terms of total land-use disturbance across the region, the Upper Waikato and Waihou Piako CMZs had the greatest exposure of bare soil, both with values of 0.31% of the sampled area (Figure 9). Exposure of bare soil by land-use activities in the Waipā and Lower Waikato CMZs made up 0.27% and 0.25% of the sampled area, respectively. Land-use disturbance in the West Coast, Lake Taupō, Central Waikato and Coromandel CMZs equated to 0.11%, 0.07%, 0.05% and 0.04% of the regions sampled area, respectively.

As evidenced in Figure 8, farm and forest tracks contributed most widely to soil disturbance at the regional scale and the same is true when examining individual CMZs (Figure 9). Tracks contributed to 66% of land-use disturbance in the Central Waikato and Lake Taupō Zones, 68% in the Coromandel, 69% in the West Coast, 72% in the Upper Waikato and 78% in the Waihou Piako. In the Lower Waikato and Waipā CMZs, tracks contributed to 57% and 61% of land-use disturbance, respectively. In terms of the area that was disturbed by tracks, the greatest exposure of bare soil occurred in the Waihou Piako (0.24% of the regions sampled area), Upper Waikato (0.22%), Waipā (0.17%) and the Lower Waikato (0.14%).

Cultivation was the next most common land-use disturbance type across management zones and was most prevalent in the Waipā (0.09% of the regions sampled area), Lower Waikato (0.07%), Upper Waikato (0.03%) and West Coast (0.01%). Disturbance by forest harvesting was most widespread in the Upper Waikato (0.023% of the regions sampled area), Lake Taupō (0.014%) and Waihou Piako CMZs (0.011%).

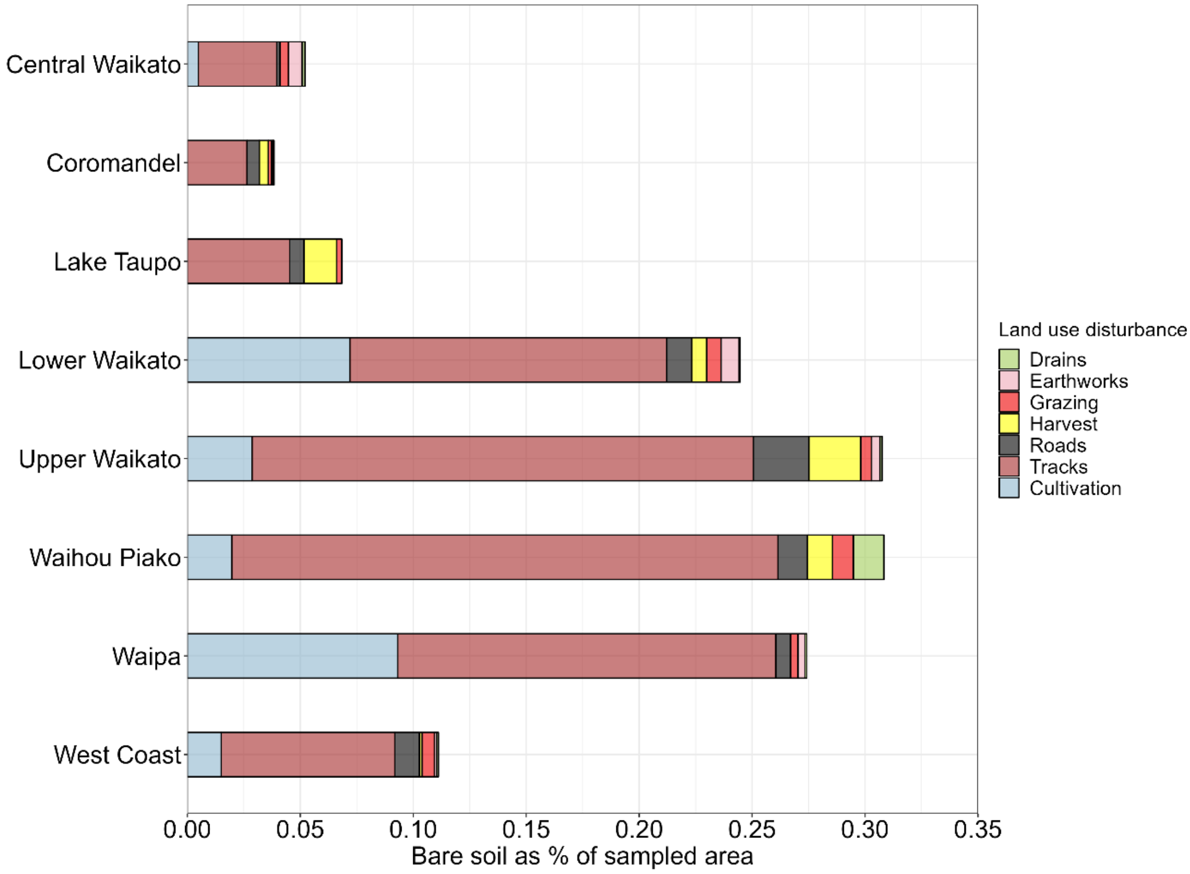


Figure 9: Disturbance caused by land-use-related activities within catchment management zones (CMZs) in the Waikato region. Note that disturbance is defined as the area of bare soil, as a proportion of the regions sample area (6,155 ha).

Disturbance by natural processes

Natural erosion processes contributed to disturbance on 9.7% of the regions sample points and resulted in 0.61% of bare soil by area. When considering actively eroding surfaces (E) and the related sub-categories of natural erosion, slope failures (landslides, debris avalanches and slump/flow) resulted in bare soil on 0.06% of the region's sampled area (Figure 10). As a proportion of the region's total natural erosion, 10% was a result of slope failures.

Gully erosion is broken down further into the sub-categories of tunnel gully, open gully, and large gully erosion, which collectively contributed to disturbance across 0.08% of the sampled area (Figure 10). As a proportion of natural disturbance across the region, 13% was the result of gully erosion processes. Riparian erosion and deposition processes (stream bank scour and stream bank deposition) resulted in disturbance across 0.06% of sampled area and contributed to 10% of disturbance by natural erosion processes (Figure 10).

Surface erosion processes (sheetwash and rockfall/exposure of bare rock) resulted in the greatest exposure of bare soil across the region with values of 0.27% and 0.1%, respectively. Overall, 61% of bare soil exposure by natural processes was a result of sheetwash (16%) and rockfall/bare rock (44%). The remaining natural erosion processes (wind erosion and geothermal) resulted in bare soil across 0.04% of the total sampled area and contributed to 7% of natural disturbance across the region.

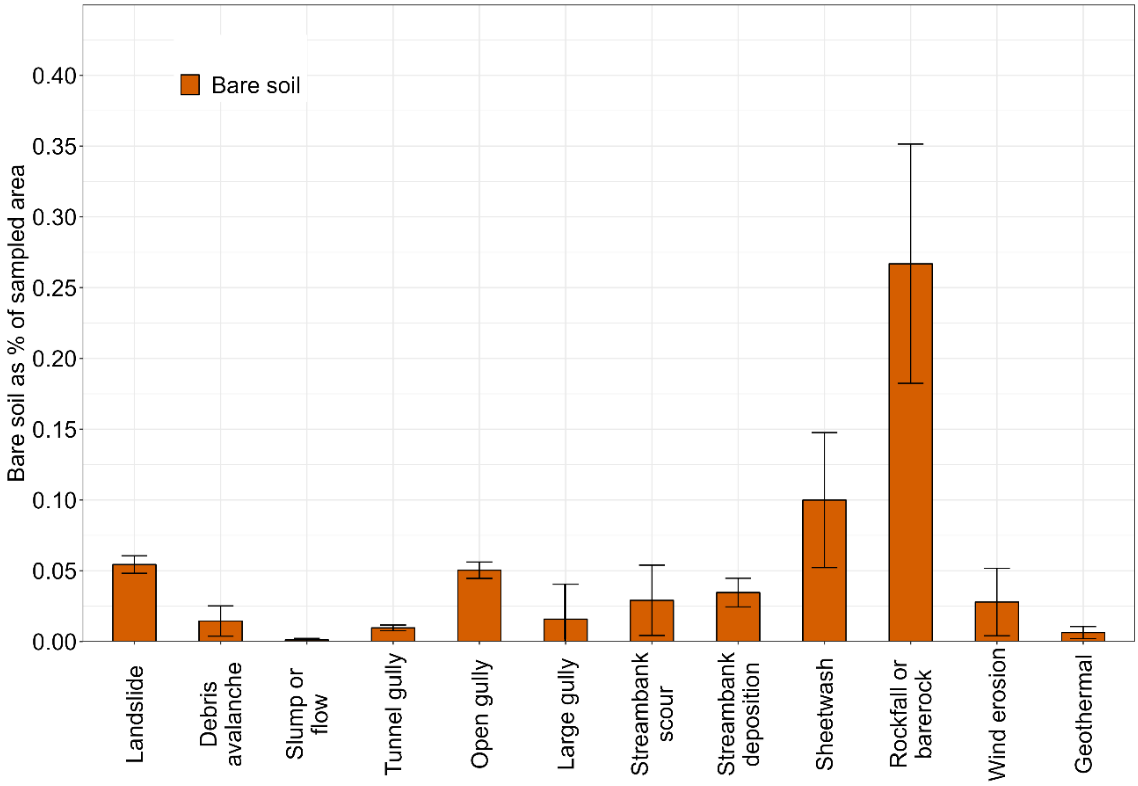


Figure 10: Bare soil resulting from natural erosion processes, expressed as a percentage of the total sampled area (6,155 ha). Error bars represent the 95% confidence intervals.

As shown in Figure 10, disturbance resulting from natural processes was most prevalent in the Lake Taupō and West Coast CMZs, with exposure of bare soil equating to 0.31% and 0.14% of the region's sample area, respectively. As a proportion of the region's natural disturbance, 51% occurred in the Lake Taupō management zone. Within the Lake Taupō management zone, 47% of natural disturbance was a result of rockfall or bare rock and 32% was a result of sheetwash processes. The high incidence of natural disturbance within the Lake Taupō management zone can be attributed to highly erodible slopes along the eastern Kaimanawa Ranges and Central Volcanic Plateau. The West Coast CMZ had the highest incidence of disturbance by landslides (0.02% of the sampled area) and open gully erosion (0.02% of the sampled area) reflecting the high erosion risk across the zone due to soft rock geology and steep slope classes (see section 3.2.1). Disturbance by wind erosion was also most common in the West Coast CMZ (0.03% of the sampled area) and can be attributed to the occurrence of sand dunes along the coastal margins.

The Waipā management zone had the third highest coverage of bare soil (0.05% of the sampled area), with bare rock/scree (0.03%), open gully erosion (0.01%) and landslides (0.006%) contributing most to natural erosion. The area of bare soil within each of the remaining CMZs (Central Waikato, Coromandel, Lower Waikato, Upper Waikato and Waihou-Piako) covered less than 0.04% of the region's sampled area, with dominant natural erosion processes being landslides, gully erosion, streambank deposition, and exposure of bare rock and scree.

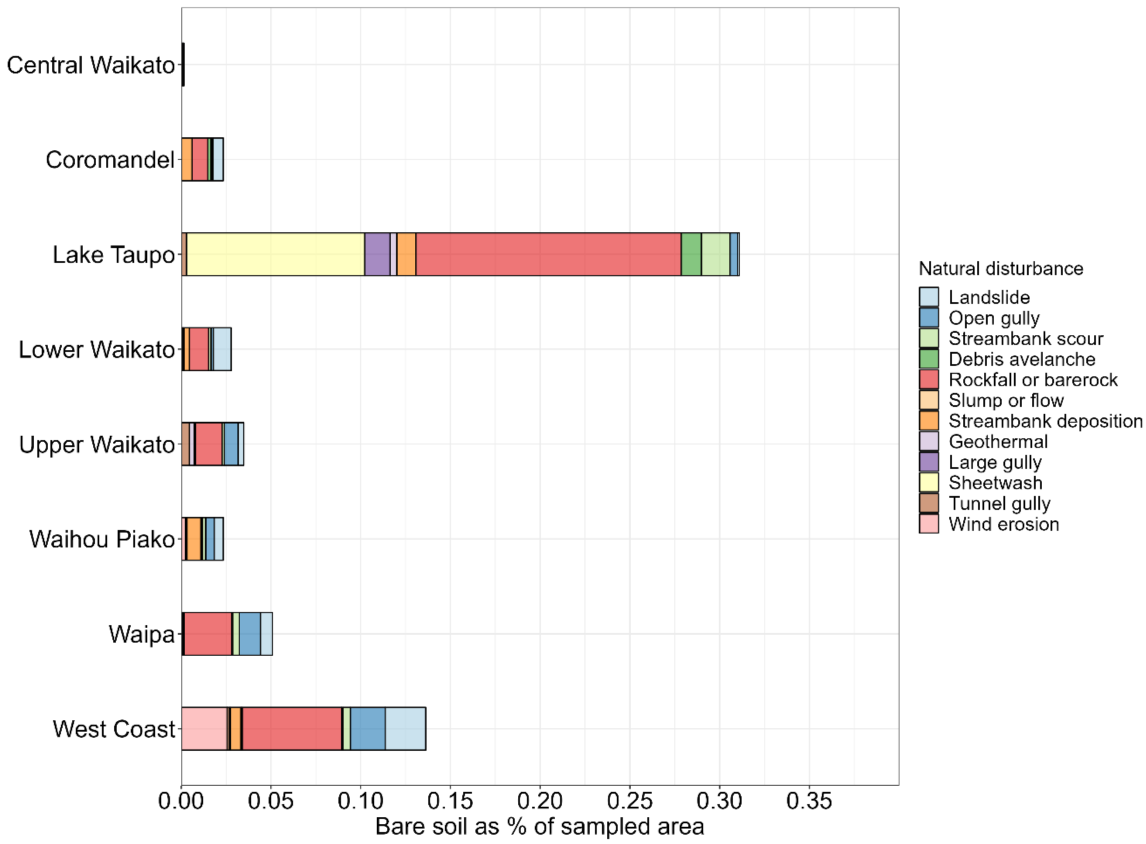


Figure 11: Disturbance caused by natural processes within Catchment Management Zones (CMZs) in the Waikato region. Note that disturbance is defined as the area of bare soil, as a proportion of the regions sample area (6155 ha).

3.4.2 Changes over time

To determine change in soil disturbance over time, the mean coverage of bare soil across sample points for each disturbance type was compared over respective survey years (2007, 2012 and 2017). The total number of survey points compared over time equated to 5,878 points. The lower repeat dataset was a result of uninterpretable datapoints during the 2007 survey due to missing aerial imagery in some parts of the region (see section 3.2).

Land-use disturbance

Table 1 shows the change in the average coverage of bare soil across sample points, broken down by disturbance type. Note that the sample size for each stratum (disturbance type) varied over time due to differences in classification across survey years. For example, 38 points were identified as being disturbed by cultivation in 2012 compared to 42 points in 2017. Therefore, comparing the average coverage of bare soil for individual strata over time is a more accurate and quantitative approach for determining change compared to the point sampling approach, which allocates a single 'summary code' to each sampling point (see section 2.2 for a full description of the survey methods).

As demonstrated in Table 1, there was a statistically significant decrease (P<0.05) in the average disturbance caused by cultivation (10.6%) and grazing (1.6%) between 2007 and 2017. In addition, the average exposure of bare soil caused by forest harvest declined by 6.8% (P<0.05) over the same 10-year period. The exposure of bare soil by farm and forest tracks remained unchanged between 2007 and 2017, although a statistically significant increase of 0.5% was observed between 2007 and 2012 (P<0.05) and similar decrease of 0.7% (P<0.05) was observed between 2012 and 2017. Disturbance by harvesting and cultivation contributed to about 90% of the total change in bare soil observed between 2007 and 2017 and demonstrates the potential impact of the timing of image acquisition on estimates of bare soil across survey years. Overall, land-use disturbance decreased significantly by 2.4% (P<0.05) over the 10-year period from 2007 to 2017.

Table 1: Change in the mean exposure of bare soil across sample grids resulting from land-use disturbance over successive survey years (2007, 2012 and 2017).

Disturbance	n	BS Area[†]	95% CI[‡]	n	BS Area[+]	95% CI[‡]	n	BS Area[+]	95% CI[‡]	Change		
		2007			2012			2017		2007-2017	2007-2012	2012 - 2017
Cultivation	110	44.5	6.3	38	25.3	9.2	42	33.9	10.8	*	*	-
Drains	46	3.6	0.6	51	2.4	0.5	34	3.3	0.7	-	*	*
Earthworks	42	10.3	3.7	29	6.9	3.3	17	8.1	4.0	-	*	-
Grazing	146	3.5	0.4	146	2.0	0.2	112	1.9	0.4	*	*	*
Harvest	74	12.5	3.3	95	6.0	1.5	64	5.7	2.1	*	*	-
Roads	64	7.4	0.9	54	7.7	0.9	63	7.3	0.8	-	-	-
Tracks	925	5.9	0.2	962	5.4	0.2	924	6.1	0.3	-	*	*
Total	1407	9.1	0.8	1375	5.7	0.4	1256	6.7	0.5	*	*	*

[†] Mean coverage (%) of bare soil across 1 ha sample grids
[‡] 95% confidence interval about the mean
n Sample number
* Statistically significant difference at P = 0.05; - No statistically significant difference at P = 0.05

Natural disturbance

Table 2 shows the mean coverage of bare soil across 1 ha sampling units and over successive sampling years (2007, 2012, and 2017). Between 2007 and 2017, the mean coverage of bare soil due to landslides, tunnel gully erosion, and streambank deposition decreased by 1.1%, 1.0% and 2.2%, respectively (P<0.05). Over the same period (2007-2017), the mean coverage of bare soil due to streambank scour increased from 2.8% to 4.1% (P<0.05). With respect to short-term changes (2012-2017), exposure of soil due to sheetwash was found to have increased by 16.9% (P<0.05) across sampling points, while bare soil due to open gully erosion decreased by 0.6% (P<0.05). All other natural erosion processes had little or no impact on exposure of freshly disturbed surfaces over the past 5 years (2012-2017).

When the exposure of freshly disturbed soil by natural processes was summed across all disturbance types, a statistically significant increase of 0.5% was observed between 2007 and 2017 and can largely be attributed to the large increases in bare soil by rockfall/bare rock and sheetwash. More long-term data is required to determine if the increase in bare soil by natural disturbance is indicative of a long-term trend or whether the change is due to improved detection of bare soil associated with improved resolution of aerial imagery.

Table 2: Change in the mean exposure of bare soil across freshly disturbed surfaces resulting from natural erosion processes over successive survey years (2007, 2012, and 2017).

Disturbance	n	BS Area††	95% CI‡	n	BS Area††	95% CI‡	n	BS Area††	95% CI‡	Change		
		2007			2012			2017		2007-2017	2007-2012	2012 - 2017
Landslide	118	3.3	0.3	149	2.2	0.2	148	2.2	0.3	*	*	-
Debris avalanche	33	4.9	2.4	19	5.4	4.4	12	7.4	6.6	-	-	-
Slump or flow	14	2.4	0.8	8	2.1	0.5	3	2.3	6.3	+	+	+
Tunnel gully	44	3.0	0.6	42	2.3	0.4	28	2.0	0.5	*	-	-
Open gully	53	3.0	0.4	79	2.3	0.3	100	2.8	0.4	-	*	*
Large gully	0	0.0	0.0	1	7.0	0.0	6	16.2	36.4	+	+	+
Streambank scour	62	2.8	0.4	51	2.4	0.5	42	4.1	3.8	*	-	-
Streambank deposition	31	7.3	1.8	39	6.4	2.0	41	5.1	1.6	*	-	-
Sheetwash	24	23.8	10.3	29	9.8	3.8	23	26.7	13.8	-	*	*
Rockfall or bare rock	61	7.9	3.5	104	6.6	2.7	151	10.3	3.5	-	-	-
Wind erosion	10	32.1	27.3	7	25.0	31.7	8	21.5	23.7	-	-	-
Geothermal	3	7.7	18.3	3	10.7	15.2	3	13.0	23.7	+	+	+
Total	**453**	**5.9**	**1.0**	**532**	**4.3**	**0.7**	**565**	**6.4**	**1.3**	*	*	-

†† Mean coverage (%) of bare soil across 1 ha sample grids
‡ 95% confidence interval about the mean
n Sample number
* Statistically significant difference at P = 0.05; - No statistically significant difference at P = 0.05
+ Insufficient data meant that change over time analysis could not be undertaken

3.4.3 Summary of key soil disturbance results

2017 results (state)

- Disturbance by land-use-related activities was observed at 21.1% of the region's sample points. Farm and forestry tracks were the most common form of disturbance, contributing to 68% of land-use disturbance across the region.
- The highest proportion of bare soil by land-use disturbance occurred in the Upper Waikato and Waihou Piako CMZs (0.31% of the regions sampled area), followed by the Waipā (0.27%) and Lower Waikato (0.25%). Land-use disturbance in the West Coast, Lake Taupō, Central Waikato and Coromandel CMZs (as a percentage of the sampled area) equated to 0.11%, 0.07%, 0.05%, and 0.04%, respectively.
- Farm and forest tracks were the most common form of land-use disturbance across all CMZs, followed by cultivation and forest harvest.
- Natural erosion processes contributed to disturbance at 9.7% of the region's sample points and resulted in 0.61% of the observed area showing exposure of bare soil. Surface erosion processes (sheetwash and rockfall/exposure of bare rock) resulted in the greatest exposure of bare soil across the region with values of 0.27% and 0.1% of the sampled area, respectively. Overall, 61% of bare soil exposure by natural processes was a result of sheetwash (16%) and rockfall/bare rock (44%).
- Disturbance caused by natural processes was most prevalent in the Lake Taupō and West Coast CMZs, with exposure of bare soil equating to 0.31% and 0.14% of the sampled area, respectively. The high incidence of natural disturbance within the Taupō management zone can be attributed to highly erodible slopes along the eastern Kaimanawa Ranges and Central Volcanic Plateau. The West Coast management zone had the highest incidence of disturbance by landslides (0.02% of the sampled area) and open gully erosion (0.02%) reflecting the high erosion risk across the zone.

Changes in soil disturbance over time (2007 – 2017)

- When comparing the proportion of bare soil across sample points, mean values decreased significantly between 2007 and 2017 for areas impacted by cultivation, grazing, and forest harvest. Overall, bare soil exposure by land-use activities decreased by 2.4% (P<0.05) over time (2007 – 2017).

- Average exposure of bare soil by natural processes increased significantly ($P<0.05$) from 5.9% in 2007 to 6.4% in 2017 and can largely be attributed to the large increases in bare soil by rockfall/bare rock and sheetwash over time.
- Further long-term data is required to better understand the drivers behind increased natural disturbance across the region.

3.5 Soil stability across land-uses in the Waikato region

3.5.1 State

An advantage of the point sample approach (Section 2.2.3) is that the coverage of different land-use types can be estimated for the region. Furthermore, soil stability, disturbance, and coverage of bare soil can be estimated for the various land-uses and is presented in the following sections for the 2017 sampling period.

Land-uses in the Waikato region

Collectively, horticulture and cropping, dairy pasture, drystock pasture, and forestry covered 62.3% of the regions sampled area (Figure 12). Dairy pasture and improved drystock pasture covered 25.5% and 22.7% of the regions sample points, respectively; while horticulture (including cropping) and forest plantations were observed at 1.7% and 12.3% of points, respectively. Natural forest and scrub were observed at 24.2% of sites and all remaining land-uses covered less than 5% of the regions sample points. A more detailed breakdown of land-use classes can be found in Table A2-8, Appendix 2.

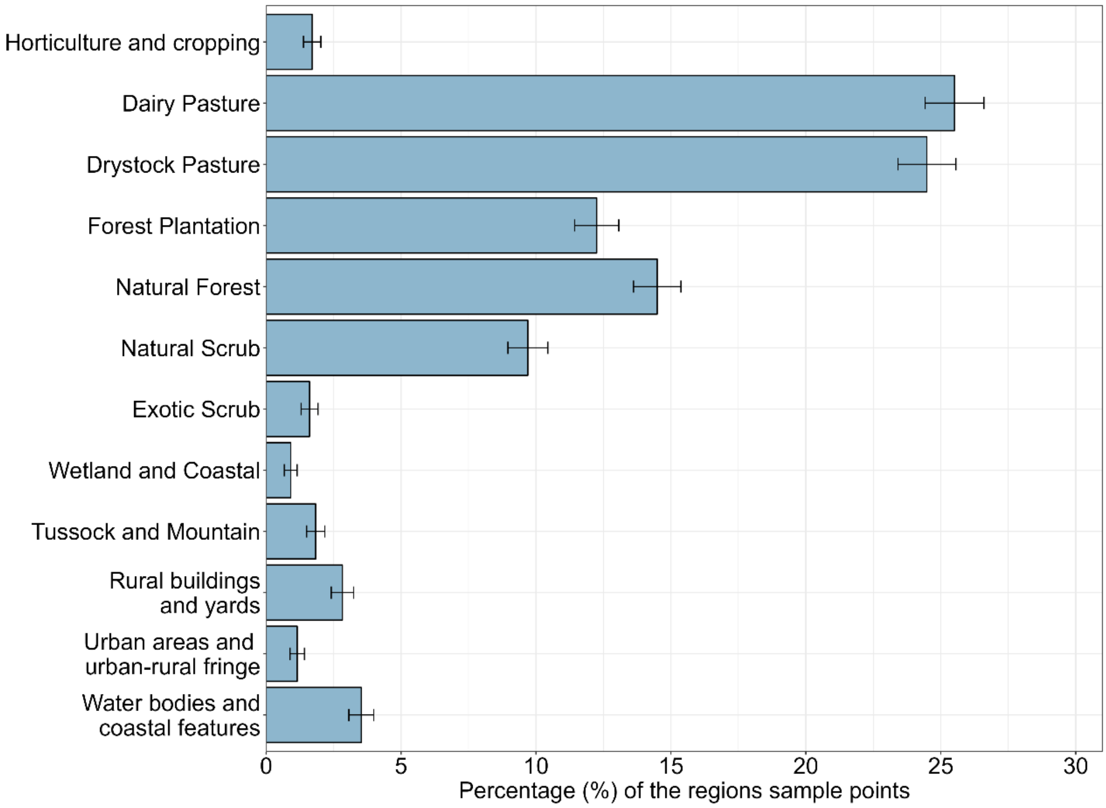


Figure 12: Percentage of the regions sample points that are in each land-use category as observed in the 2017 survey.

Soil stability by land-use category

Figure 13 shows a breakdown of soil stability classes by land-use type. Dairy sites had the most points that were classified as 'stable' (20.6% of the regions sample), followed by drystock (9.9%), plantation forestry (7.1%), natural forest (5.9%), and natural scrub (3.4%). Although dairy and drystock pasture occurred at a similar number of points, drystock pasture had a significantly greater number of points that were identified as being unstable (U, R, and E in Figure 13). Of the regions 6,155 sample points, 5.6% were classified as eroding (E) drystock pasture compared to

1.1% for dairy pasture, 0.7% for natural forest, and 0.8% for tussock and mountain. The higher proportion of eroding slopes under drystock compared to dairy is not unexpected given that drystock systems tend to occur on steeper slopes and/or more erodible hill-country. Moreover, an analysis of land-use capability (LUC) classes for respective land-use types found that 44% of the points identified as 'improved drystock pasture' were classified as unstable and occurred on LUC class 6e,7e, and 8e land. In comparison, only 7% of the points that were identified as dairy were classified as unstable and occurred on the steeper LUC class 6e,7e, and 8e land.

The occurrence of freshly eroded surfaces (E) under forest plantation, natural forest, and natural scrub was considerably lower compared to drystock pasture (Figure 13). The percentage of points under forest plantation that were freshly eroded was 0.4% compared to 5.6% for drystock land, even though 71% of exotic forest occurred on LUC 6e,7e, and 8e land, compared to 44% for drystock pasture.

Most points (83%) observed under horticulture and cropping occurred on stable land, and the remaining 17% were located on erosion prone land (Figure 13). Natural forest, natural scrub and 'tussock and mountain' occupied 40% of points classified as 'steep' (LUC classes 6,7, and 8) and made up 13% of the points that were actively eroding (E).

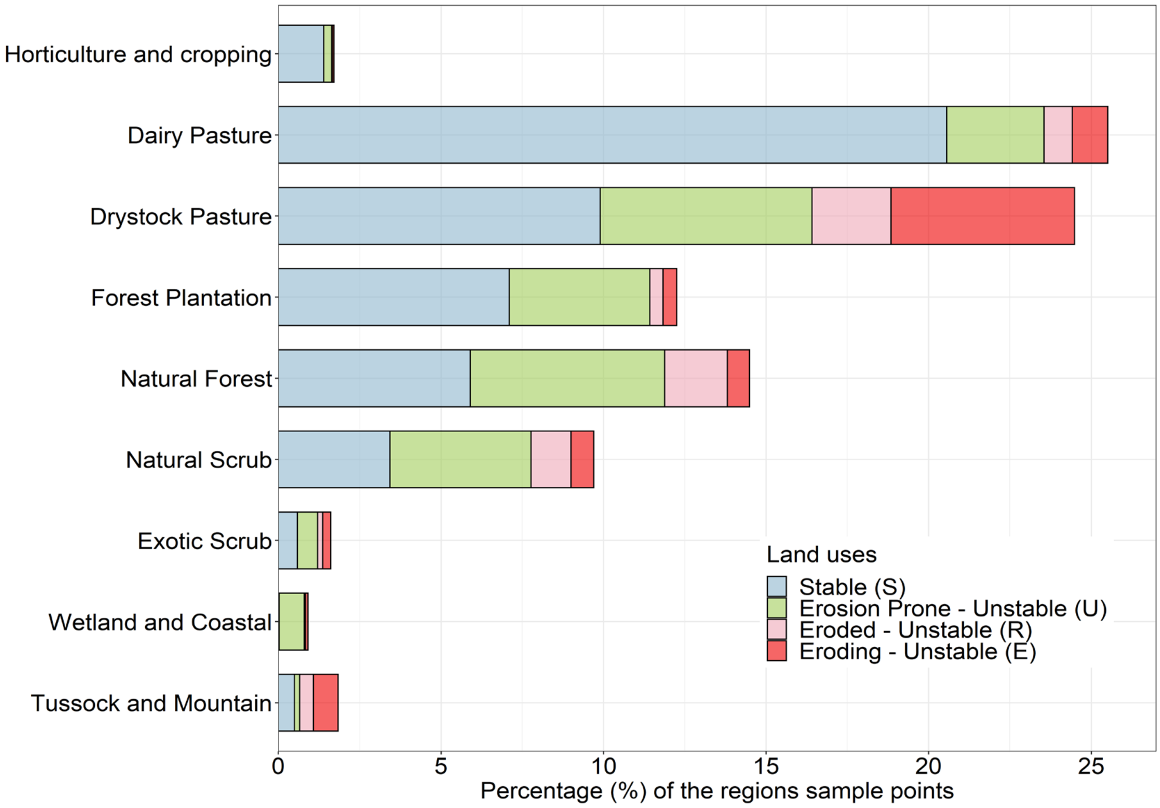


Figure 13: Percentage of the regions sample points that contained stable (S), erosion prone (U), eroded (unstable – R) and actively eroding (E) land.

3.5.2 Changes over time

Land-uses in the Waikato region

Over the 10-year period from 2007 to 2017, there was a statistically significant increase (2.2%) in points classified as 'dairy' ($P<0.05$) and a corresponding decrease in sites classified as 'drystock' ($P<0.05$; Figure 14). This finding is consistent with land-use data, which demonstrates an increase in dairy pasture from 2007 to 2017 within the Waikato region in response to intensification of pastoral land-uses and conversion of drystock pasture to dairy pasture (Ministry for the Environment, 2021). The percentage of points with natural forest increased significantly from 2007 to 2017, while natural scrub and exotic scrub have declined steadily over time, most likely in response to vegetation growth and reclassification of these points to natural forest in latter surveys (Figure 14). Horticulture/cropping, tussock/mountain, and wetland/coastal vegetation showed little or no change between survey years. Plantation forestry showed small but statistically significant changes between survey years and is likely a result of changes in coverage associated with planting and harvesting cycles.

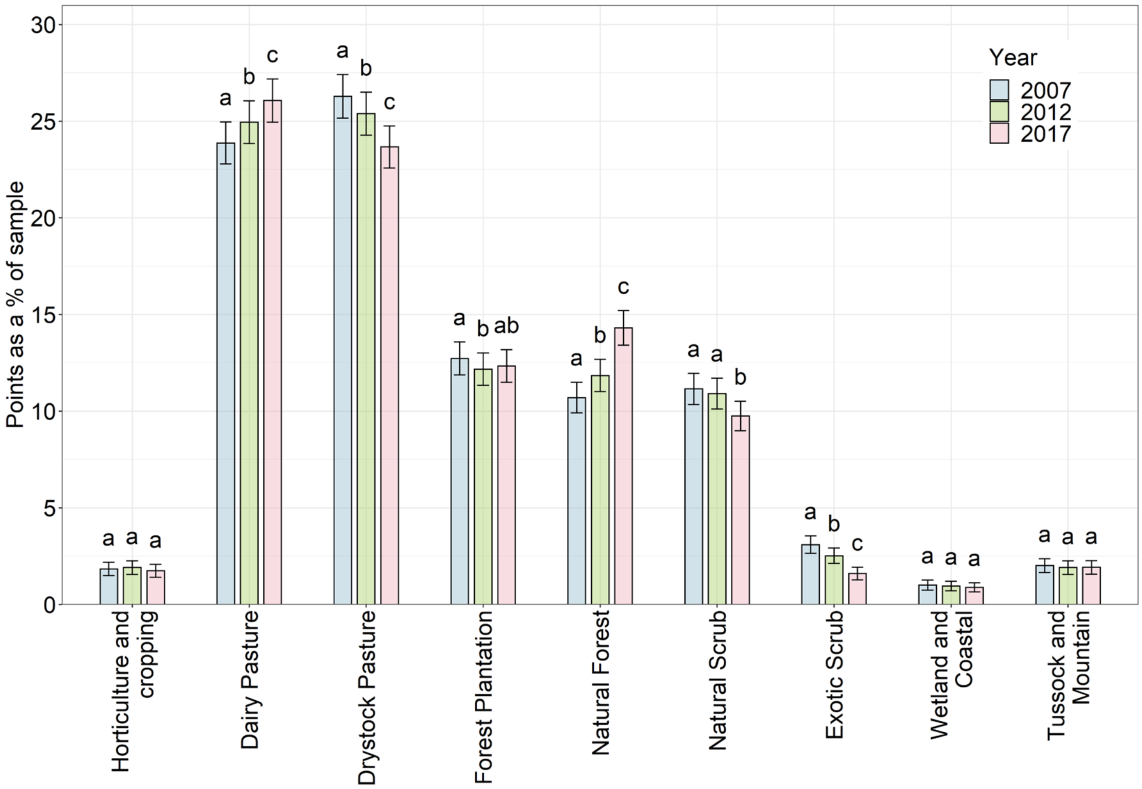


Figure 14: Change in the classification of surveyed points over successive survey years from 2007 to 2017. Letters indicate whether there is a statistically significant (P<0.05) difference between survey years.

Soil stability by land-use category

Figure 15 shows the percentage of points that were classified as 'unstable' for respective land-use categories. Note that unstable land is defined as land that is erosion prone (inactive and vegetated unless disturbed by land-use activities), eroded (recently disturbed but revegetating), and/or eroding (freshly disturbed surfaces). Unstable land under drystock saw no change between 2007 and 2017. However, there was an increase in the proportion of unstable points under dairy pasture over the same period. The increase in unstable points under dairy pasture can be attributed to unstable land previously under drystock being converted to dairy. Despite the long-term increase in unstable land in dairy systems, there was no measurable change between 2012 and 2017.

The proportion of unstable land under forest plantation fluctuated over time (decrease of 0.7% between 2007 and 2012 and an increase of 0.6% between 2012 and 2017). Short-term changes in the classification of stability classes under forestry is expected given the changes in forest cover (see Figure 14) between survey years and importantly the proportion of unstable land has not increased over the long term (2007 – 2017). Natural forest had a significant increase in 'unstable land' between 2012 and 2017, most likely a result of reclassified erosion-prone scrubland (exotic and natural) to forest during the most recent survey. Changes in the coverage of 'unstable' land for remaining land-uses were negligible and no significant changes were detected over time.

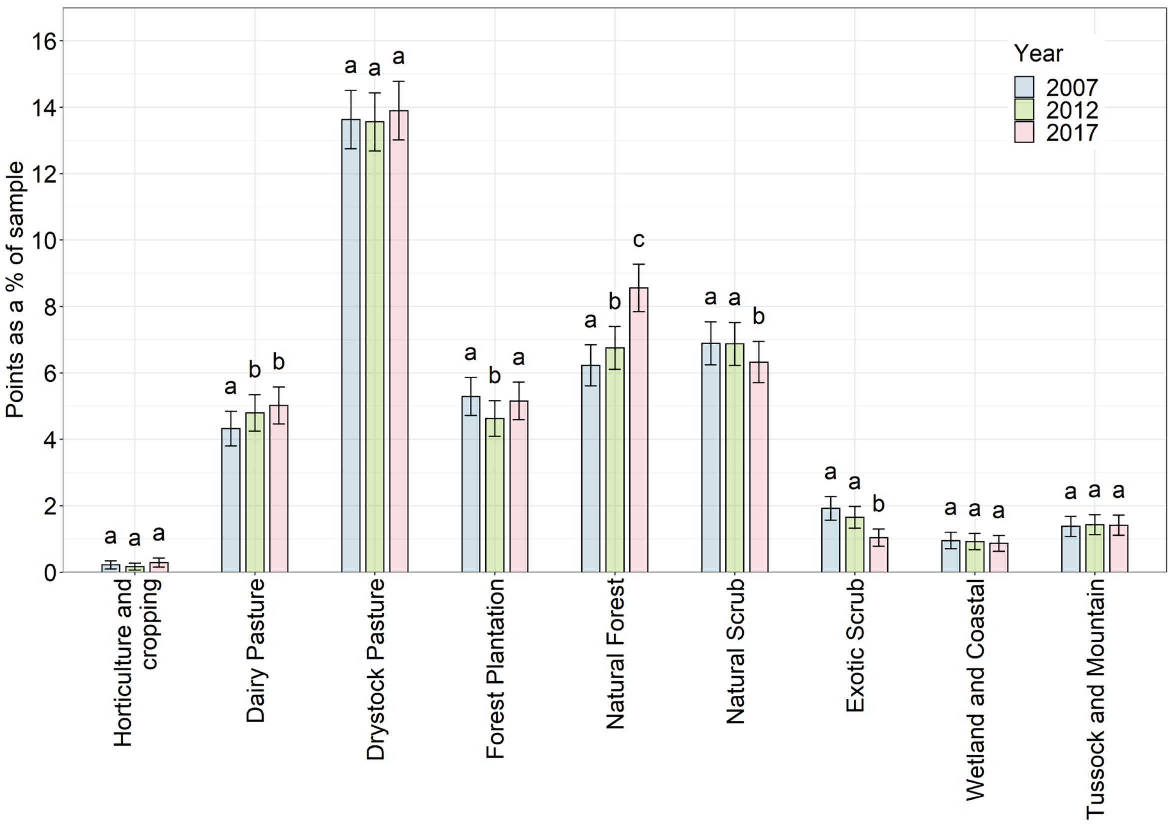


Figure 15: Change in the percentage of points identified as 'unstable' and across a range of land-uses in the Waikato region.

3.5.3 Summary of key soil stability results for individual land-use types

Land-use coverage

- Predominant land-use types in the Waikato include dairy pasture (25.5%), drystock pasture (24.5%), natural forest (14.5%) and forest plantation (12.3%).

Soil stability

- Dairy sites had the most points that were classified as 'stable' (20.7% of the regions sample), followed by drystock (9.9%), plantation forestry (7.1%), natural forest (5.9%), and natural scrub (3.4%).
- Drystock pasture had the highest percentage of actively eroding land (5.7% of the regions sample points), followed by dairy (1.1%), tussock and mountain (0.8%), and natural forest (0.7%).

Changes in land-use coverage and soil stability by land-use (2007 – 2017)

- Over the 10-year period, from 2007 to 2017, there was a 2.2% increase in the coverage of dairy pasture ($P<0.05$) and a similar decrease of 2.6% ($P<0.05$) in the coverage of drystock pasture.
- Natural forest increased significantly from 10.7% in 2007 to 14.3% in 2017 ($P<0.05$).
- Dairy pasture and natural forest saw increases in the percentage of points classified as 'unstable' between 2007 and 2017. For dairy farms, a significant increase in 'unstable' surfaces occurred between 2007 and 2012 but not between 2012 and 2017. The increase in 'unstable' surfaces between 2007 and 2012 is most likely due to unstable land previously under drystock being converted to dairy. The increase in unstable points under natural forest is likely due to the reclassification of shrubland (exotic and native) to natural forest over time.

3.6 Soil disturbance across land-uses in the Waikato region

3.6.1 State

The proportion of bare soil across respective land-use categories is shown in Figure 16 and a summary for each land-use type is provided below. Note that bare soil values represent the amount of bare soil across each land-use type as a proportion of the region's sampled area (6,155 ha). Source data for Figure 16 can be found in Appendix 2 (Table A2-9). Overall, soil disturbance was highest across dairy and drystock land, with values of 0.78% and 0.46%, respectively. In fact, 34% and 20% of bare soil across the region occurred on dairy and drystock land, respectively. Land-use-related activities contributed to 95% of overall disturbance across dairy sites, with the remaining 5% of bare soil resulting from natural erosion processes. In comparison, 40% of bare soil across drystock land was due to natural disturbance and 60% was a result of land-use disturbance.

Bare soil across forestry plantations made up 0.18% of the region's sampled area, with 93% of bare soil across forestry sites caused by land-use disturbance and 7% due to natural disturbance. Exposure of bare soil on horticultural land covered 0.13% of the sample area and almost all bare soil (99%) was a result of land-use disturbance. On land covered by natural forest, natural scrub or exotic scrub, bare soil made up less than 0.1% of the region's sampled area, with both land-use activities (predominantly tracks) and natural erosion processes contributing to similar amounts of disturbance. Across tussock and mountain areas, bare soil covered 0.28% of the sample area and contributed to 12% of soil disturbance across the region, with all bare soil being a result of natural disturbance. Bare soil across wetlands and coastal margins covered 0.03% of the sampled area, with 91% of bare soil resulting from natural disturbance and 9% from land-use activities.

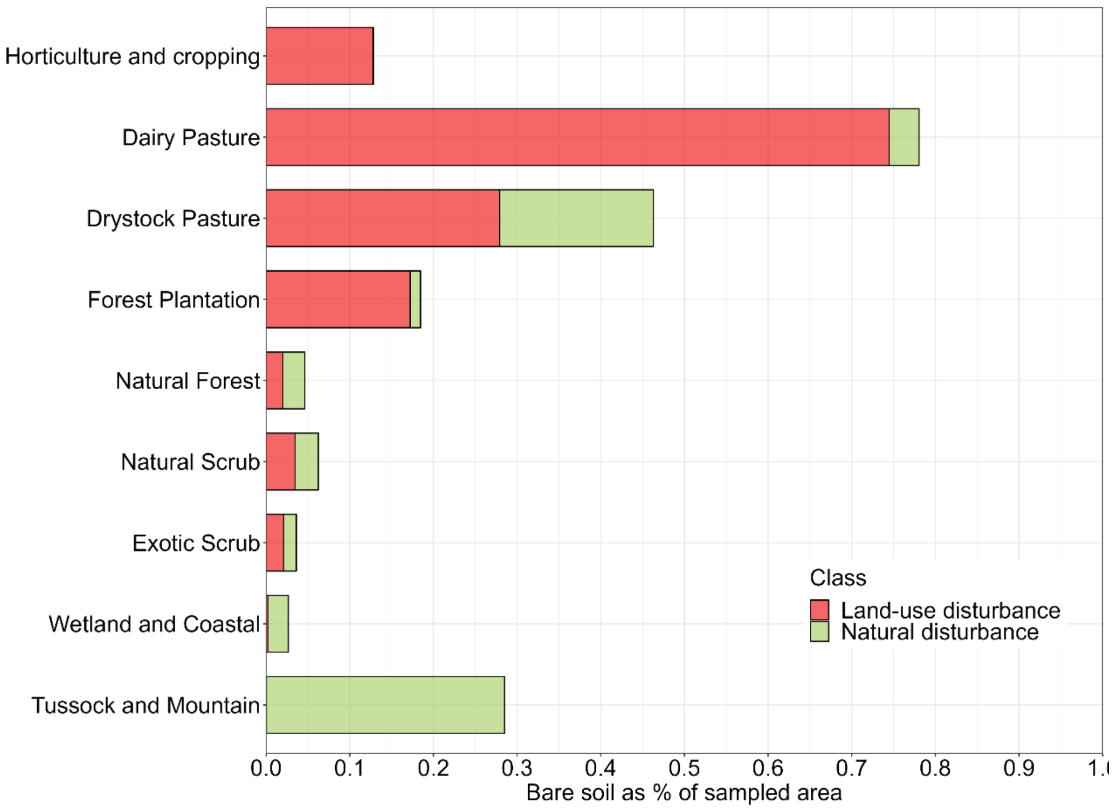


Figure 16: Proportion of bare soil resulting from land-use and natural disturbance types on land-uses across the region. Note that bare soil values represent bare soil as a proportion of the regional total in 2017 (6,155 ha).

In the sections below, the broad disturbance categories (i.e. land-use disturbance and natural disturbance) are broken down into individual disturbance types to better understand the causes and drivers behind the exposure of bare soil across respective land-use types.

Bare soil casued by land-use activities

During the 2017 survey, dairy systems had the highest proportion of bare soil caused by land-use-related activities (0.75% of the sampled area), followed by drystock (0.3%), forest plantations (0.17), and horticulture/cropping (0.13%, Figure 17). As a percentage of the sampled area, all other land-uses (natural forest, natural scrub, exotic scrub, wetland/coastal vegetation, and tussock/mountain vegetation) had less than 0.05% bare soil resulting from land-use activities. When excluding rural buildings and yards from the analysis, farm tracks alone contributed to 77% of bare soil on dairy farms and 37% on drystock farms. The high proportion of disturbance by tracks reiterates the importance of correctly managing tracks/laneways across multiple land-uses. Tracks/laneways provide a potential sediment source and transport mechanism for nutrient and other contaminants from critical source areas to waterways. For dairy farms, laneways have been shown to be a potentially important source of stream contaminants, particularly during summer when stream flows are low and water temperatures are warmer (Monaghan & Smith, 2012). Similarly, for forestry and drystock pasture, poorly managed tracks on steeper slopes are a sediment source and provide a pathway for sediment transport from erosion prone areas to waterways.

Across horticultural, dairy, and drystock land, exposure of bare soil by cultivation covered 0.23% the region's sampled area. Overall, 17% of land-use disturbance and 8% of total disturbance across the region was caused by cultivation. Across forest plantations, harvesting caused bare soil on 0.05% of the total sampled area, which equates to 4% of land-use disturbance and 2% of total disturbance across the region.

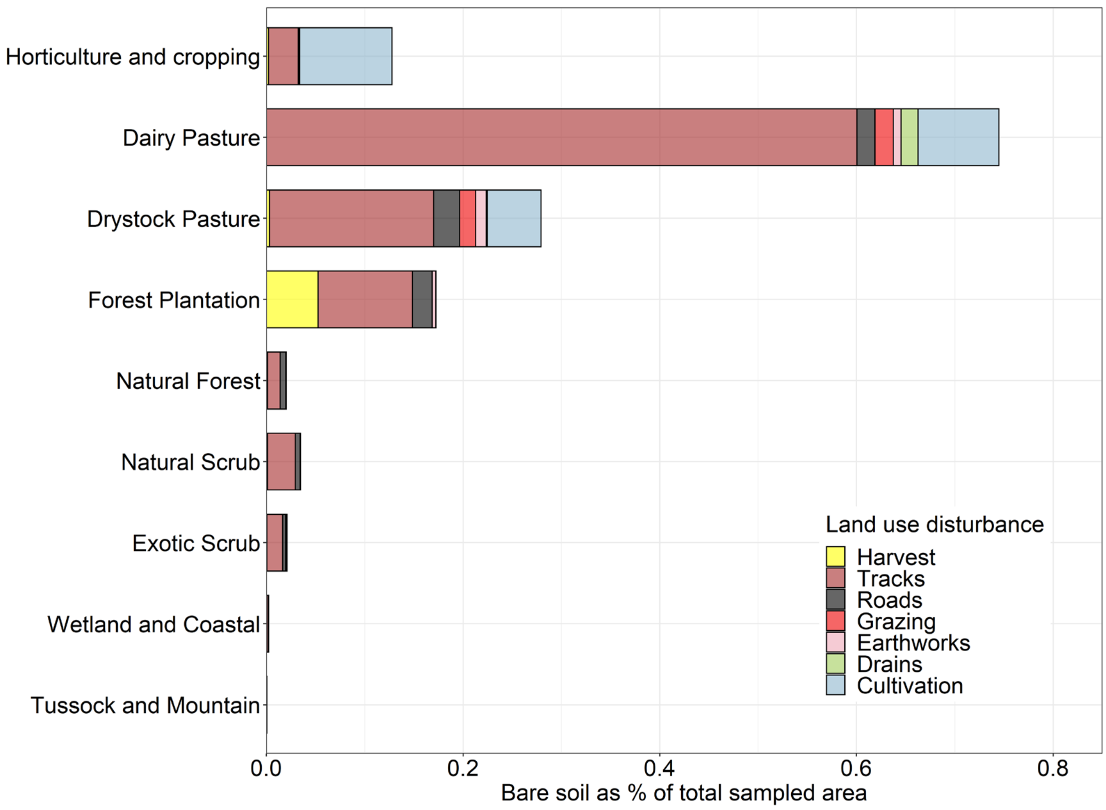


Figure 17: Bare soil resulting from land-use activities, as a percentage of the total sampled area in 2017 (6,155 ha)

Bare soil caused by natural erosion processes
As a percentage of the sampled area, tussock and mountain areas had the highest proportion of bare soil (0.28%), followed by drystock pasture (0.18%), and dairy pasture (0.04%, Figure 18). For the remaining land-uses (horticultural/cropping, forestry, natural forest, natural scrub, exotic scrub and wetland/coastal vegetation) the proportion of bare soil was less than 0.03%.

Across all land-uses, surface erosion processes (sheetwash and rock/scree deposits) contributed to 66% of natural disturbance , followed by gully erosion (tunnel gully, large gully, and open gully - 13%), slope failure (slump or flow, debris avelanches, and landslides - 11%), and riparian processes (stream bank cour and stream bank deposition - 10%). In tussock and mountain areas, sheetwash and bare rock/scree were the most common form of natural disturbance contributing to 0.1% and 0.14% of the region's sampled area respectively. On drystock land, bare rock/scree was also the most common form of natral erosion, contributing to 0.1% of the regions sampled area, followed by open gully erosion (0.03%), and land sliding (0.04%). For coastal areas, bare soil by wind erosion was most prevalent (0.02%) due to the occurrence of coastal sand dunes along the west coast. Bare soil exposure by natural processes across horticultural/cropping sites was neglagible, reflecting the low slope land that dominates these areas.

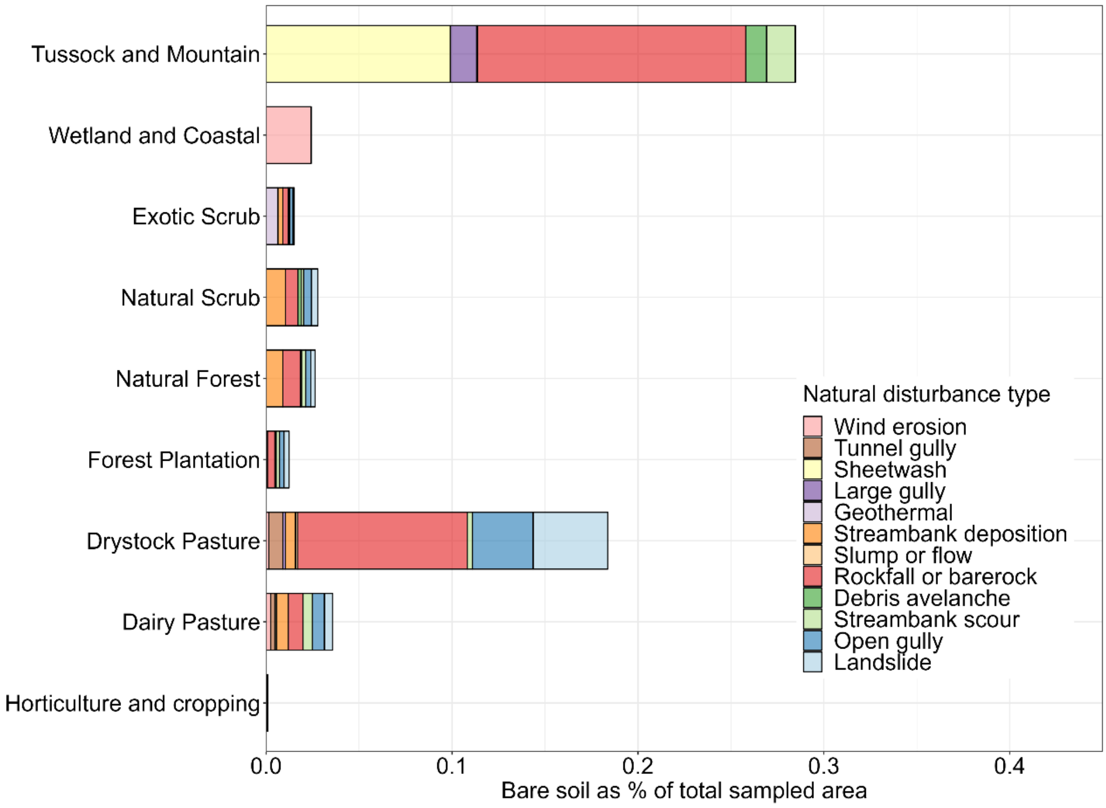


Figure 18: Bare soil resulting from natural erosion processes, as a percentage of the total sampled area in 2017 (6,155 ha)

3.6.2 Changes over time

Land-use activities
Figure 19 shows the impact of land-use activities on bare soil over time. In terms of the average coverage of bare soil across the sampled area, there was a statistically significant decrease in bare soil under horticultural sites (including cropping) over the 10-year period from 2007 to 2017. This is consistent with the findings discussed in section 3.4.2, which demonstrated a significant decrease in cultivation between 2007 and 2012, most likely a result of differences in image acquisition dates and resulting differences in the capture of freshly cultivated land.

Between 2007 and 2012, there was a significant decrease in bare soil resulting from land-use activities across dairy and drystock sites. This decrease could be, in part, due to differences in the timing of aerial image acquisition. Both dairy and drystock systems saw an increase (P<0.05) in mean coverage of bare soil between 2012 and 2017, However, over the 10-year period (2007 to 2017) a general decreasing trend in bare soil coverage was observed for drystock systems (P<0.05) but not for dairy systems. The area of bare soil under forestry decreased between 2007 and 2017 and is likely a result of differences in harvesting cycles between survey years. All other land-uses (natural forest, natural scrub, and exotic scrub) saw varying degrees of change over time, but no statistically significant differences were observed.

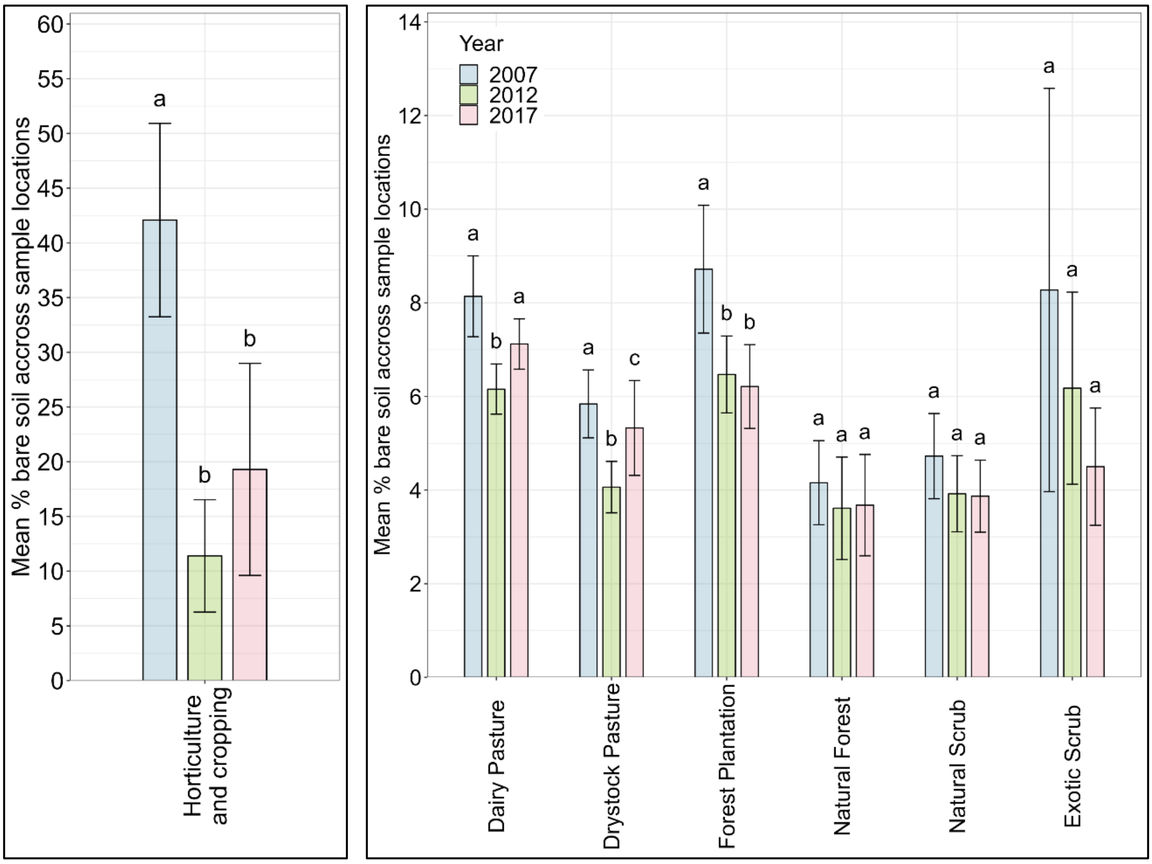


Figure 19: Change in the mean proportion of bare soil caused by land-use disturbance, across sampling units, by land-use. Note that the mean values represent the average proportion (%) of bare soil for a 1 ha sampling unit, rather than as a proportion of the total sampled area.

Natural erosion processes

Figure 20 shows the change in the mean area of bare soil across major land-use types that were impacted by natural erosion processes. Between 2007 and 2017, there was no change in the exposure of bare soil by natural erosion processes for dairy, natural forest, natural scrub, and exotic scrub. Drystock farms and forestry sites had relatively small but statistically significant decreases in mean coverage of bare soil across respective sampled areas. However, drystock sites had seen no change in bare soil coverage over the past 5 years (2012-2017). Bare soil across tussock and mountain sites varied considerably within survey years, as indicated by the large confidence intervals. Nevertheless, natural erosion appeared to increase significantly over the past 5-year and 10-year periods across sites.

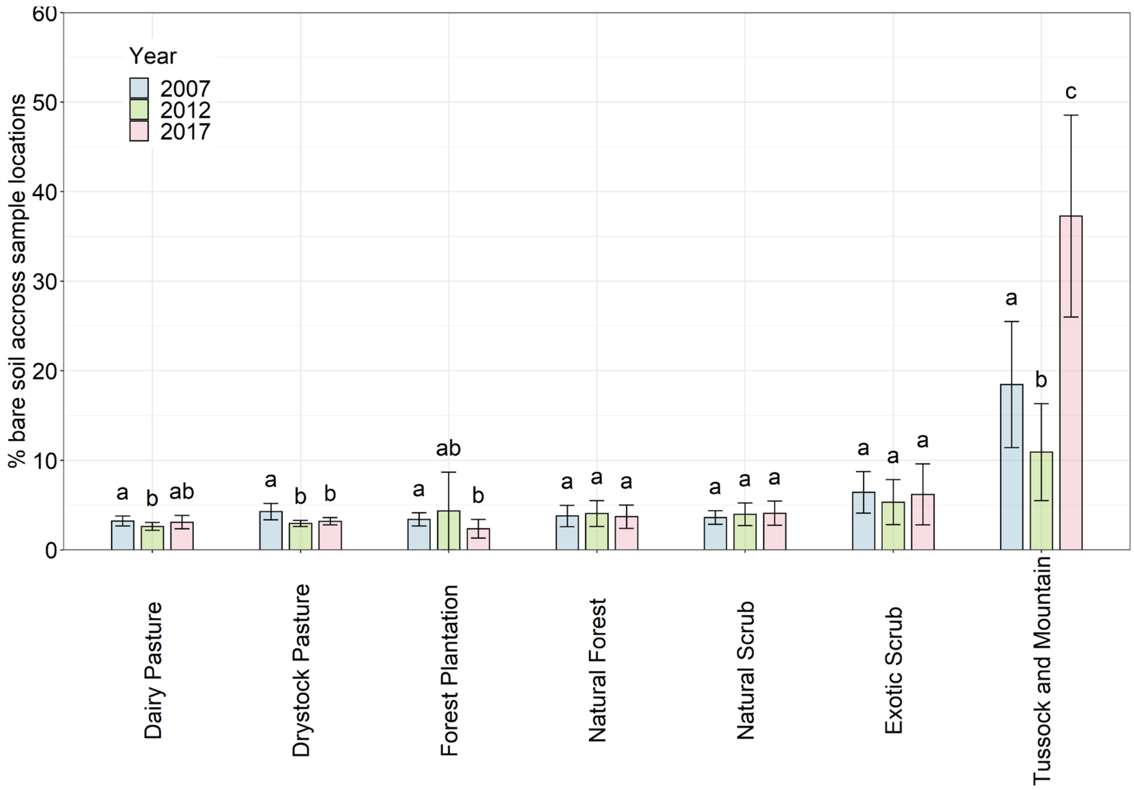


Figure 20: Change in the mean proportion of bare soil caused by natural disturbance processes, across sampling units, by land-use. Mean values represent the average proportion (%) of bare soil for a 1 ha sampling unit, and error bars represent the 95% confidence interval around the mean. Note that wetland and coastal areas were excluded from the analysis due to low sample numbers.

3.6.3 Summary of key soil disturbance results for individual land-use types

2017 results (state)

- As a percentage of the region's sampled area, dairy and drystock farms had the most disturbance, with values of 0.78% and 0.46%, respectively. Across the region, 34% of bare soil was on dairy land and 20% on drystock land.
- Forest plantations occurred on 12.3% of the regions sample points. About 8% of soil disturbance across the region occurred across forest plantations.
- Exposure of bare soil on horticultural land covered 0.13% of the sampled area and almost all bare soil (99%) was a result of land-use disturbance.
- Dairy farms had the greatest exposure of bare soil caused by land-use-related activities (0.75% of the sampled area), followed by drystock (0.3%), forest plantations (0.17%), and horticulture/cropping (0.13%).
- Farm tracks contributed most to land-use disturbance, contributing to 68% of bare resulting from land-use activities.
- Surface erosion processes (sheetwash, wind erosion, rock/scree deposits, and geothermal) contributed most (66%) to bare soil rusulting from natral erosion.

Changes over time (2007 to 2017)

- Exposure of bare soil due to cultivation on horticulture/cropping land decreased significantly between 2007 and 2017 and is most likely a result of differences in image acquisition dates and resulting differences in the capture of freshly cultivated land.
- Between 2007 and 2017, there was a statistically significant reduction in bare soil caused by land-use disturbance on horticultural land, drystock pasture, and forestry plantations.
- Between 2007 and 2017, bare soil resulting from natural processes decreased significantly across forestry sites and is likely a result of differences in harvest/planting cycles between survey years. Tussock and mountain areas had a significant increase in bare soil between

2007 and 2017 and this could be attributed to differences in the interpretation of 'bare soil and rock' between survey years. Results should be treated with caution in relation to tussock and mountain areas due to the large variance in measurements as indicated by the large confidence intervals.

4 Summary, conclusions, and recommendations

4.1 Region-wide state and trend

The most recent 2017 survey indicated that 49% of the 6,155 surveyed points in the Waikato Region were classified as stable, while 26% contained unstable points that showed evidence of historic erosion but were inactive at the time of the survey. In terms of eroding surfaces, 7.5% of points contained eroding surfaces that were revegetating and 9.4% of points were actively eroding with evidence of freshly disturbed soil. The remaining 7.5% of sample points included urban areas (1.2%), rural buildings and yards (2.8%), and waterbodies and coastal features (3.5%).

The proportion of stable sites across the Waikato Region remained unchanged between 2007 and 2012. However, over the 10-year period from 2007 to 2017, there was 2% decrease in stable surfaces. Erosion prone surfaces (those that are at risk to natural erosion but currently inactive) increased by 3.5% from 2007 to 2017 and correlated with a 2.2% decrease in eroded surfaces over the same period, indicating revegetation and stabilisation of these slopes over time. The occurrence of major storm events and changing land-use management (e.g. increased conservation planting) between successive survey years is likely a key driver in the coverage of stable versus unstable slopes.

With respect to Individual disturbance types, tracks/laneways remain the largest contributor to land-use disturbance across the region, particularly across dairy and drystock farms. The latest 2017 results showed that 77% of bare soil exposure on dairy farms and 37% on drystock farms occurred on laneways/tracks. Collectively, tracks on dairy, drystock, and forest plantations contributed to 92% of land-use disturbance across sample points. Tracks/laneways provide a potential sediment source and transport mechanism for nutrient and contaminants from critical source areas to waterways and correct management of these areas (e.g. ensuring adequate buffer zones between tracks and waterways) is essential for mitigating nutrient and sediment loss.

Overall, the number of intact surfaces (those that show no evidence of disturbance) increased by 2.5% between 2007 and 2017. For land-use disturbance, the mean coverage of freshly exposed soil across sample points decreased significantly over the 10-year period, from 9.1% in 2007 to 6.7% in 2017 and can be attributed to significant decreases in disturbance resulting from harvest, grazing pressure, and cultivation. However, it is acknowledged that differences in exposure of bare soil between survey years is highly dependent on the timing of aerial image acquisition during respective surveys and more long-term data is required to determine whether observed changes in the current report are consistent with long-term trends. In terms of the exposure of bare soil by natural erosion processes, a significant increase in mean coverage of bare soil across sample points was observed between 2007 and 2017, with the increases associated with rockfall/bare rock and streambank scour. Over the most recent survey period (2012-2017), there was no change in exposure of bare soil by natural erosion processes and it is possible that the long-term increase is a consequence of several damaging and erosive storms that occurred between 2007 and 2012. However, further data is required to better understand the mechanisms driving changes in natural erosion processes (e.g. the increasing frequency of highly erosive storm events associated with climate change).

4.2 Management zone differences

When data was aggregated by Catchment Management Zone (CMZ), the West Coast CMZ had the highest proportion of unstable land (69% of the surveyed points), followed by the Taupō (50%), Lower Waikato (44%), and Waipā (42%) CMZs. The high incidence of unstable land on the West Coast is not surprising given that much of the area comprises steep hill-country pasture and soft sedimentary geology.

Farm tracks were the most common form of land-use disturbance, resulting in exposed soil in at least 57% of land-use disturbance across all CMZs. Cultivation was the second most common land-use disturbance type across management zones and was most prevalent in the Waipā (0.09% of the regions sampled area), Lower Waikato (0.07%), Upper Waikato (0.03%) and West Coast (0.01). Overall, the Upper Waikato and Waihou Piako CMZs had the greatest exposure of bare soil by land-use activities, both with values of 0.31%.

In terms of natural disturbance, exposure of bare soil from natural processes was most prevalent in the Lake Taupō and West Coast CMZs, with exposure of bare soil equating to 0.31% and 0.14% of the sampled areas, respectively. In fact, 51% of the regions natural disturbance occurred in the Lake Taupō management zone. Within the Lake Taupō management zone, 47% of natural disturbance was a result of rockfall or bare rock and 32% was a result of sheetwash processes. The high incidence of natural disturbance within the Lake Taupō management zone can be attributed to highly erodible slopes along the eastern Kaimanawa Ranges and Central Volcanic Plateau. The West Coast management zone had the highest incidence of disturbance by landslides (0.02%) and open gully erosion (0.02%) reflecting the high erosion risk across the zone due to soft rock geology and steep slope classes.

4.3 Impact of land-use on soil stability and disturbance

As a percentage of the region's sampled area, dairy and drystock farms had the highest amount of disturbance, with values of 0.78% and 0.46%, respectively. Land-use-related activities contributed most to overall disturbance across dairy sites, with 95% of disturbance caused by land-use activities and 5% by natural erosion. In comparison, drystock had a higher proportion of disturbed sites impacted by natural erosion (40%). Over the 10-year period from 2007 to 2017, land-use disturbance decreased significantly on horticulture/cropping, drystock pasture, and forest plantations, which demonstrated a decrease in total land-use disturbance across the region.

Disturbance due to natural erosion processes decreased over time (2007 – 2017) for drystock pasture and forest plantations but increased significantly for tussock and mountain areas. Overall, natural disturbance was found to increase across the region and appears to be closely related to large increases in bare soil across tussock and mountain areas, despite no change in the coverage of this land-use. Therefore, more long-term data is required to determine whether changes in bare soil associated with tussock and mountain areas are associated with differences in surveyor interpretation between respective surveys or whether natural erosion is indeed increasing in these areas.

4.4 Survey design review

The Waikato Regional Council soil stability survey provides robust estimates of the state and trend of soil stability and disturbance in the region on a five-yearly cycle. The robust methodology developed by Burton et al. (2009) ensures accurate estimates of soil stability and disturbance attributes, both regionally and for domains of interest such as a land-use and management zones. The regional soil stability survey was carried out at a scale of 0.25 points per $km^{2,}$ based on overlaying 6,155 points over a 2 km x 2 km matrix across the region. The current design is sufficient for estimating state and trend in soil stability attributes at the regional scale. However, it is recommended that pre-existing data gaps for the 2007 survey are retrospectively filled to ensure the repeat dataset can be increased to 6,122 points. Furthermore, the 2002 soil stability data was excluded from the current round of analysis due to differences in the survey methodology employed during the survey. For example, some disturbance codes were amended in the survey method between 2002 and 2007. Therefore, it is recommended that the 2002 data is updated to ensure that soil disturbance codes are consistent with subsequent surveys, which will increase the size of the WRC soil stability dataset and improve the overall assessment of soil stability/disturbance across the region.

In terms of data processing, a recently developed R coding platform is the preferred method for aggregation and analysis of attributes due to the robustness, efficiency, and transparency of the code. It is envisioned that the newly developed R code will be utilised for future surveys to ensure consistency in the reporting approach and enable additional analyses as the size of the dataset increases over time.

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6 Appendices

Appendix 1 - Definitions of indicators

Data recording codes and procedures

Attribute codes used in the survey are those promulgated in the document 'Land and Soil Monitoring: A Guide for SOE and Regional Council Reporting' (Land Monitoring Form New Zealand), hereinafter referred to as the 'LMF manual'. The attribute codes are further expanded on below.

Point number

A unique reference number for each sample point, from 1 to 6122 is assigned by the Waikato Regional Council GIS system. The identification number for each discreet point is 'locked' and therefore consistent transferable over successive monitoring years.

Grid reference

The grid overlay is the same as used in previous surveys. The grid reference for each sample point is expressed as an 8-digit 'easting' and 'northing', derived by applying a NZTM (New Zealand Transverse Mercator) map-grid layer over the aerial photograph GIS layer, and selecting points spaced two kilometres apart at map grid intersections.

Soil stability

The four soil stability codes outlined in Chapter 4 of the LMF manual were used to analyse soil stability. These are:

S stable surfaces (vegetated)
U erosion-prone unstable surfaces (inactive, vegetated)
R eroded unstable surfaces (recently disturbed, revegetating)
E eroding unstable surfaces (freshly disturbed, bare)

Nature of disturbance

Standard codes defined in Chapter 4 of the LMF manual were used to record the nature of disturbance. These are:

Topsoil:
c exposed by cultivation
x exposed by harvest
y exposed by spraying
z exposed by grazing
t exposed by farm or forest track (not sealed)
r exposed by road (not sealed)
d exposed by drain excavation, cleaning, or tile drainage
e exposed by earthworks

The 'r' code is additional to codes outlined in the LMF manual, the purpose of which is to differentiate between farm tracks and public roads.

Subsoil:
l landslide or slip
u slump or flow
a debris avalanche
p tunnel (under-runner)
g open gully

Other:

bs streambank scour
bd streambank deposition
w wind erosion or deposition of sand
s sheetwash
br rockfall or rock outcrops
ge geothermal

The code 'ge' (geothermal) has been added, consistent with previous surveys.

Percentage bare ground

Percentage bare ground was recorded by the procedure recommended in the LMF manual (i.e. using a 10 x 10 grid of points superimposed as a GIS layer on a one hectare area around each ortho-photo sample point).

Land-use

The LMF manual provides a base-set of codes for recording land-use. These same codes have been used in this survey, except that:

- orchards and vineyards (o) have been differentiated into 4 separate codes, - orchards(miscellaneous) 'o', avocado orchards 'oa', grape vineyards 'ov', and kiwifruit vineyards 'ok'. In the 2002 survey, only the 'o' code was used for orchards and vineyards.
- the code 'gf' has been used in this survey to differentiate green-feed crops from grain crops ('g').
- 'sf' (ground-fern) and 'sa' (sub-alpine scrub) have been differentiated from natural scrub (s).
- 'mg' (saline wetland vegetation) has been differentiated from coastal scrub and grass (m).

The other LMF manual codes for recording non-vegetated land-use have been used, with the addition of 'bs' (bare sand) and 'br' (bare rock). Urban areas (u) have been differentiated into 'ui' (industrial/commercial buildings and yards), 'uh' (houses and associated gardens), and 'uo' (parks and reserves). Also 'bg' (indoor agriculture) has been differentiated into 'bh' (glasshouses/shadehouses) and 'ba' (poultry barns, pig sheds, etc.).

Associated vegetation

The same codes as above have been used for recording secondary vegetation, using the annotations provided in the LMF manual.

Landform

The landform codes in the LMF manual have been used in this survey, with the following exceptions:

- a code for plateaux (dp) has been used instead of downland (d) for a few points on broad undulating ridges within hill country or steeplands.
- the code 'a' denoting river or stream has been differentiated into 'la' (large river – alluvial), 'sa' (small river or stream – alluvial), 'lr' (large river – rock channel) and 'sr' (small river or stream – rock channel).
- a code for drains (dr) has been added.

These same codes have been applied in the previous three surveys.

Data analysis

Data storage

Sample point locations were stored as ArcGIS metadata. These are cross-referenced to a screen display (shapefile) which shows their locations relative to region-wide orthophotos and map layers (e.g. topographic); and a database (attribute table) which contains data recorded for all points. This data is transferable to an Excel spreadsheet to enable data sorting.

Sorts

An initial data sort is required in an Excel spreadsheet, to check for consistency in use of codes, and correct where necessary. Further work is required to:

- repeat spreadsheet procedures described below, which were used to analyse and compare previous surveys, OR
- duplicate their output if it is possible to do that through a statistical software package.

Point counts

Subsidiary spreadsheets need to be created region-wide for each land-use (e.g. dairy pasture). These are required to be repeatedly sorted to count points in each category of interest (i.e. soil stability, nature of disturbance).

Statistical analysis

Formulae are applied in each spreadsheet, enabling calculation of percentages and error margins for each category of interest.

Data presentation

Sort, point count, and statistical analysis results for particular topics need to be stored as four series of summary spreadsheets (soil stability, soil disturbance, changes in stability, and changes in disturbance). Each report's tables were sourced from these spreadsheets.

Appendix 2 – Tables

Table A2- 1: Soil stability across the Waikato region in 2017

Regional summary 2017	Points	Points as % of sample[1]	95% CI[1]	Bare soil as % of area[2]	95% CI[1]
Stable surfaces (S)					
S (i) with intact soil	2104	34.2	1.2	0.00	0.00
S (ii) with soil disturbed by land-use-related activities	934	15.2	0.9	1.09	0.09
Erosion-prone surfaces (U)					
U (i) with intact soil	1220	19.8	1.0		
U (ii) with soil disturbed by land-use-related activities	377	6.1	0.6	0.32	0.04
Eroded and eroding surfaces (R+E)					
R (i) with re-vegetating soil	463	7.5	0.7		
E (ii) with soil disturbed by natural processes	595	9.7	0.7	0.61	0.12
Extensively disturbed surfaces					
Rural buildings and yards	174	2.8	0.4	0.19	0.07
Urban areas and urban-rural fringe	71	1.2	0.3	0.01	0.01
Water bodies and coastal features	217	3.5	0.5	0.09	0.06
All regions sample points	6155	100.0		2.31	

[1] CI = 95% confidence interval
* Statistically significant at P= 0.05

Table A2- 2: Soil stability across Catchment Management Zones (CMZs) in the Waikato region.

CMZ	Surface Stability	Number of points	Points as % of total within each CMZ
Central Waikato	Stable surfaces	95	81.9
Central Waikato	Unstable surfaces (erosion-prone)	12	10.3
Central Waikato	Unstable surfaces (eroded)	4	3.4
Central Waikato	Unstable surfaces (eroding)	5	4.3
Central Waikato	**Total**	**116**	
Coromandel	Stable surfaces	198	42.9
Coromandel	Unstable surfaces (erosion-prone)	176	38.1
Coromandel	Unstable surfaces (eroded)	53	11.5
Coromandel	Unstable surfaces (eroding)	35	7.6
Coromandel	**Total**	**462**	0.0
Lake Taupo	Stable surfaces	311	45.0
Lake Taupo	Unstable surfaces (erosion-prone)	189	27.4
Lake Taupo	Unstable surfaces (eroded)	108	15.6
Lake Taupo	Unstable surfaces (eroding)	83	12.0
Lake Taupo	**Total**	**691**	
Lower Waikato	Stable surfaces	370	55.4
Lower Waikato	Unstable surfaces (erosion-prone)	214	32.0
Lower Waikato	Unstable surfaces (eroded)	21	3.1
Lower Waikato	Unstable surfaces (eroding)	63	9.4
Lower Waikato	**Total**	**668**	

Table A2-2 (continued)

CMZ	Surface Stability	Number of points	Points as % of total within each CMZ
Upper Waikato	Stable surfaces	676	65.1
Upper Waikato	Unstable surfaces (erosion-prone)	227	21.9
Upper Waikato	Unstable surfaces (eroded)	59	5.7
Upper Waikato	Unstable surfaces (eroding)	76	7.3
Upper Waikato	**Total**	1038	
Waihou Piako	Stable surfaces	648	68.8
Waihou Piako	Unstable surfaces (erosion-prone)	218	23.1
Waihou Piako	Unstable surfaces (eroded)	28	3.0
Waihou Piako	Unstable surfaces (eroding)	48	5.1
Waihou Piako	**Total**	942	
Waipa	Stable surfaces	415	56.8
Waipa	Unstable surfaces (erosion-prone)	168	23.0
Waipa	Unstable surfaces (eroded)	60	8.2
Waipa	Unstable surfaces (eroding)	88	12.0
Waipa	**Total**	731	
West Coast	Stable surfaces	320	30.9
West Coast	Unstable surfaces (erosion-prone)	389	37.6
West Coast	Unstable surfaces (eroded)	130	12.6
West Coast	Unstable surfaces (eroding)	196	18.9
West Coast	**Total**	1035	

Table A2- 3: Soil stability in the Waikato region in 2002, 2007 and 2012

Surface stability	Points as % of sample	95% CI[1]	Points as % of sample	95% CI[1]	Points as % of sample	95% CI[1]	Change		
	2007		2012		2017		2007-2017	2007-2012	2012-2017
Stable surfaces	51.8	1.3	51.7	1.3	49.7	1.3	*	-	*
Unstable surfaces (erosion-prone)	23.5	1.1	22.0	1.1	25.5	1.1	*	*	*
Unstable surfaces (eroded)	9.6	0.8	9.7	0.8	7.5	0.7	*	-	*
Unstable surfaces (eroding)	7.7	0.7	9.1	0.7	9.5	0.8	*	*	-
Other surfaces	7.3	0.7	7.5	0.7	7.7	0.7	*	-	*

[1] CI = 95% confidence interval

* Statistically significant at P= 0.05, - Not statistically significant

Table A2- 4: Percentage of points and exposure of bare soil by land-use-related activities across the Waikato region in 2017.

Disturbance type	Points as % of sample	95% CI[1]	Bare soil as % of sample	95% CI
Cultivation	0.71	0.21	0.23	0.07
Drains	0.55	0.19	0.02	0.00
Earthworks	0.29	0.13	0.02	0.01
Grazing	1.88	0.34	0.04	0.01
Harvest	1.06	0.26	0.06	0.02
Roads	1.09	0.26	0.08	0.01
Tracks	15.55	0.91	0.95	0.04
Total	21.14	1.02	1.40	0.10

[1] CI = 95% confidence interval

Table A2- 5: Exposure of bare soil by land-use activities across Catchment Management Zones (CMZs) in the Waikato region in 2017.

Zone	Disturbance type	Bare soil as % of regional sample area	Bare soil as % of total bare soil resulting from land-use activities within each CMZ*
Central Waikato	Cultivation	0.00	9.4
Central Waikato	Drains	0.00	2.5
Central Waikato	Earthworks	0.01	11.6
Central Waikato	Grazing	0.00	7.2
Central Waikato	Roads	0.00	2.8
Central Waikato	Tracks	0.03	66.6
Central Waikato	**Total**	**0.05**	
Coromandel	Drains	0.00	1.3
Coromandel	Earthworks	0.00	1.7
Coromandel	Grazing	0.00	3.8
Coromandel	Roads	0.01	14.4
Coromandel	Tracks	0.03	68.6
Coromandel	Harvest	0.00	10.2
Coromandel	**Total**	**0.04**	
Lake Taupo	Drains	0.00	0.0
Lake Taupo	Grazing	0.00	3.3
Lake Taupo	Roads	0.01	9.3
Lake Taupo	Tracks	0.05	66.2
Lake Taupo	Harvest	0.01	21.2
Lake Taupo	**Total**	**0.07**	
Lower Waikato	Cultivation	0.07	29.4
Lower Waikato	Drains	0.00	0.2
Lower Waikato	Earthworks	0.01	3.3
Lower Waikato	Grazing	0.01	2.6
Lower Waikato	Roads	0.01	4.5
Lower Waikato	Tracks	0.14	57.3
Lower Waikato	Harvest	0.01	2.7
Lower Waikato	**Total**	**0.24**	
Upper Waikato	Cultivation	0.03	9.3
Upper Waikato	Drains	0.00	0.3
Upper Waikato	Earthworks	0.00	1.2
Upper Waikato	Grazing	0.00	1.5
Upper Waikato	Roads	0.02	8.0
Upper Waikato	Tracks	0.22	72.2
Upper Waikato	Harvest	0.02	7.5
Upper Waikato	**Total**	**0.31**	
Waihou Piako	Cultivation	0.02	6.4
Waihou Piako	Drains	0.01	4.3
Waihou Piako	Earthworks	0.00	0.1
Waihou Piako	Grazing	0.01	3.0
Waihou Piako	Roads	0.01	4.2
Waihou Piako	Tracks	0.24	78.4
Waihou Piako	Harvest	0.01	3.6
Waihou Piako	**Total**	**0.31**	

* Calculated by dividing the area of bare soil for each land-use disturbance type by the total area of bare soil within each CMZ.

Table A2-5 (continued)

Zone	Disturbance type	Bare soil as % of regional sample area	Bare soil as % of total bare soil within each CMZ*
Waipa	Cultivation	0.09	34.0
Waipa	Drains	0.00	0.3
Waipa	Earthworks	0.00	1.1
Waipa	Grazing	0.00	1.2
Waipa	Roads	0.01	2.4
Waipa	Tracks	0.17	61.0
Waipa	Total	0.27	
West Coast	Cultivation	0.01	13.5
West Coast	Drains	0.00	0.7
West Coast	Earthworks	0.00	0.9
West Coast	Grazing	0.01	5.0
West Coast	Roads	0.01	9.8
West Coast	Tracks	0.08	69.1
West Coast	Harvest	0.00	1.0
West Coast	Total	0.11	

* Calculated by dividing the area of bare soil for each land-use disturbance type by the total area of bare soil within each CMZ.

Table A2- 6: Percentage of points and exposure of bare soil by natural processes across the Waikato region in 2017.

Disturbance type	Points as % of sample	95% CI[1]	Bare soil as % of sample	95% CI
Debris avalanche	0.19	0.11	0.01	0.01
Geothermal	0.05	0.06	0.01	0.00
Landslide	2.52	0.39	0.05	0.01
Large gully	0.10	0.08	0.02	0.02
Open gully	1.79	0.33	0.05	0.01
Rockfall or bare rock	2.65	0.40	0.27	0.08
Sheetwash	0.37	0.15	0.10	0.05
Slump or flow	0.05	0.06	0.00	0.00
Streambank deposition	0.68	0.21	0.03	0.01
Streambank scour	0.75	0.22	0.03	0.02
Tunnel gully	0.47	0.17	0.01	0.00
Wind erosion	0.13	0.09	0.03	0.02
Total	9.75	0.74	0.61	0.12

[1] CI = 95% confidence interval

Table A2- 7: Exposure of bare soil by natural disturbance across Catchment Management Zones (CMZs) in the Waikato region in 2017.

Zone	Disturbance type	Bare soil as % of regional sample area	Bare soil as % of total bare soil within each CMZ*
Central Waikato	Landslide	0.000	33.333
Central Waikato	Open_gully	0.001	55.556
Central Waikato	Streambank_scour	0.000	11.111
Central Waikato	Total	0.001	
Coromandel	Landslide	0.006	24.306
Coromandel	Open_gully	0.001	2.778
Coromandel	Streambank_scour	0.000	2.083
Coromandel	Debris_avalanche	0.002	7.639
Coromandel	Rockfall_or_barerock	0.009	37.500
Coromandel	Slump_or_flow	0.000	0.000
Coromandel	Streambank_deposition	0.006	25.694
Coromandel	Total	0.023	

* Calculated by dividing the area of bare soil for each land-use disturbance type by the total area of bare soil within each CMZ.

Table A2-7 (continued)

Zone	Disturbance type	Bare soil as % of regional sample area	Bare soil as % of total bare soil resulting from land-use activities within each CMZ*
Lake Taupo	Landslide	0.001	0.314
Lake Taupo	Open_gully	0.004	1.361
Lake Taupo	Streambank_scour	0.016	5.131
Lake Taupo	Debris_avalanche	0.011	3.613
Lake Taupo	Rockfall_or_barerock	0.148	47.539
Lake Taupo	Streambank_deposition	0.011	3.403
Lake Taupo	Geothermal	0.004	1.204
Lake Taupo	Large_gully	0.014	4.555
Lake Taupo	Sheetwash	0.099	31.937
Lake Taupo	Tunnel_gully	0.003	0.942
Lake Taupo	Total	0.311	
Lower Waikato	Landslide	0.010	35.673
Lower Waikato	Open_gully	0.001	4.678
Lower Waikato	Streambank_scour	0.001	4.678
Lower Waikato	Rockfall_or_barerock	0.011	38.596
Lower Waikato	Streambank_deposition	0.003	11.111
Lower Waikato	Large_gully	0.001	2.339
Lower Waikato	Sheetwash	0.001	2.924
Lower Waikato	Total	0.028	
Upper Waikato	Landslide	0.003	8.879
Upper Waikato	Open_gully	0.008	21.963
Upper Waikato	Streambank_scour	0.001	3.738
Upper Waikato	Rockfall_or_barerock	0.015	42.991
Upper Waikato	Streambank_deposition	0.001	1.869
Upper Waikato	Geothermal	0.003	7.477
Upper Waikato	Tunnel_gully	0.005	13.084
Upper Waikato	Total	0.035	
Waihou Piako	Landslide	0.005	21.528
Waihou Piako	Open_gully	0.005	20.139
Waihou Piako	Streambank_scour	0.002	8.333
Waihou Piako	Debris_avalanche	0.000	0.694
Waihou Piako	Rockfall_or_barerock	0.001	2.778
Waihou Piako	Streambank_deposition	0.008	32.639
Waihou Piako	Large_gully	0.000	2.083
Waihou Piako	Tunnel_gully	0.000	1.389
Waihou Piako	Wind_erosion	0.002	10.417
Waihou Piako	Total	0.023	
Waipa	Landslide	0.007	13.141
Waipa	Open_gully	0.012	23.077
Waipa	Streambank_scour	0.004	7.372
Waipa	Debris_avalanche	0.001	1.282
Waipa	Rockfall_or_barerock	0.026	51.603
Waipa	Slump_or_flow	0.000	0.641
Waipa	Streambank_deposition	0.001	1.603
Waipa	Tunnel_gully	0.001	1.282
Waipa	Total	0.051	
West Coast	Landslide	0.023	16.607
West Coast	Open_gully	0.019	14.217
West Coast	Streambank_scour	0.004	3.106
West Coast	Debris_avalanche	0.001	0.478
West Coast	Rockfall_or_barerock	0.055	40.621
West Coast	Slump_or_flow	0.001	0.597
West Coast	Streambank_deposition	0.006	4.301
West Coast	Large_gully	0.000	0.358
West Coast	Tunnel_gully	0.001	0.956
West Coast	Wind_erosion	0.026	18.757
West Coast	Total	0.136	

* Calculated by dividing the area of bare soil for each land-use disturbance type by the total area of bare soil within each CMZ.

Table A2- 8: Percentage of sampled points under different land-uses across the Waikato region in 2017.

Land-use	Points	Points as % of sample	95% CI[1]
Horticulture and cropping	105	1.71	0.32
Dairy pasture	1570	25.51	1.09
Drystock pasture	1507	24.48	1.07
Forest plantations	754	12.25	0.82
Natural forest	892	14.49	0.88
Natural scrub	597	9.70	0.74
Exotic scrub	99	1.61	0.31
Tussock and mountain	113	1.84	0.34
Wetland and coastal	56	0.91	0.24
Rural buildings and yards [2]	174	2.83	0.41
Urban areas [2]	71	1.15	0.27
Water bodies and coastal features [2]	217	3.53	0.46
Whole Region	**6155**	**100**	

[1] 95% confidence interval for percentage of the regions sample points

[2] Extensively disturbed areas

Table A2- 9: percentage of points showing evidence of land-based disturbance and natural disturbance and exposure of bare soil as a percentage of the total sampled area, broken down by land-use type.

		Impacts of land-use on soil disturbance and bare soil			Impacts of natural processes on soil disturbance and bare soil		
	Percentage of points without any disturbance[1]	**Points**	**Area of land disturbed by use as % of region's sample points**	**Bare soil as % of region's sample area (6,155 ha)**	**Points**	**Area of land disturbed by use as % of region's sample points**	**Bare soil as % of region's sample area (6,155 ha)**
Rural uses							
Hort	0.96	43	0.7	0.13	3	0.0	0.00
Dairy	13.96	640	10.4	0.74	71	1.2	0.04
Drystock	13.58	325	5.3	0.28	346	5.6	0.18
Plantation	9.02	171	2.8	0.17	28	0.5	0.01
Sub-total	**37.52**	**1179**	**19.2**	**1.32**	**448**	**7.3**	**0.23**
Conservation uses							
Natural_Forest	13.27	32	0.5	0.02	43	0.7	0.03
Natural_Scrub	8.12	55	0.9	0.03	42	0.7	0.03
Exotic_Scrub	0.91	28	0.5	0.02	15	0.2	0.02
Wetland_Coastal	0.75	5	0.1	0.00	5	0.1	0.02
Tussock_Mntn	1.06	1	0.0	0.00	47	0.8	0.28
Sub-total	**24.11**	**121**	**2.0**	**0.08**	**152**	**2.5**	**0.38**
Other							
Rural buildings and yards	0	174	2.8	0.19	0	0.0	0.00
Urban areas and urban-rural fringe	0	71	1.2	0.01	0	0.0	0.00
Water bodies and coastal features	0	0	0.0	0.00	217	3.5	0.09
Sub-total		**245**	**4.0**	**0.20**	**217**	**3.5**	**0.09**
Regional total	**61.63**	**1545**	**25**	**2**	**817**	**13**	**1**

Table A2- 10: Change in land-use types as a percentage of total sample points in the Waikato region between 2007 and 2017.

Land-use type	Points as % of sample	95% CI[1]	Points as % of sample	95% CI[1]	Points as % of sample	95% CI[1]	Change		
	2007		2012		2017		2007-2017	2007-2012	2012-2017
Dairy	23.9	1.1	24.9	1.1	26.1	1.1	*	*	*
Drystock	26.3	1.1	25.4	1.1	23.7	1.1	*	*	*
Exotic_Scrub	3.1	0.4	2.5	0.4	1.6	0.3	*	*	*
Hort	1.8	0.3	1.9	0.3	1.7	0.3	-	-	-
Natural_Forest	10.7	0.8	11.8	0.8	14.3	0.9	*	*	*
Natural_Scrub	11.1	0.8	10.9	0.8	9.7	0.8	*	-	*
Plantation	12.7	0.9	12.2	0.8	12.3	0.8	-	*	-
Tussock_Mntn	2.0	0.4	1.9	0.3	1.9	0.4	-	-	-
Wetland_Coastal	1.0	0.3	1.0	0.2	0.9	0.2	-	-	-

[1] CI = 95% confidence interval

* Statistically significant at P= 0.05, - Not statistically significant

Table A2- 11: Change in "other" land-use types as a percentage of total sample points in the Waikato region between 2007 and 2017.

Land-use type	Points as % of sample	95% CI[1]	Points as % of sample	95% CI	Points as % of sample	95% CI	Change		
	2007		2012		2017		2007-2012	2012-2017	2007-2017
Rural buildings and yards	2.57	0.40	2.65	0.41	2.82	0.42	*	-	*
Urban areas and urban-rural fringe	1.04	0.26	1.12	0.27	1.21	0.28	*	-	-
Water bodies and coastal features	3.73	0.48	3.71	0.48	3.67	0.48	-	-	-
Total	7.33	0.67	7.49	0.67	7.71	0.68	*	-	*

[1] CI = 95% confidence interval

* Statistically significant at P= 0.05, - Not statistically significant

Table A2- 12: Individual disturbance types across all sampled land-uses in the Waikato region

Land-use class	Disturbance	Disturbance type	Number of points	points as % of regional total	bare soil as % of regions sample area
Dairy	Disturbance free	Landslide	11	0.18	0.00
Dairy	Disturbance free	Large_gully	1	0.02	0.00
Dairy	Disturbance free	Open_gully	18	0.29	0.00
Dairy	Disturbance free	Slump_or_flow	2	0.03	0.00
Dairy	Disturbance free	Streambank_deposition	1	0.02	0.00
Dairy	Disturbance free	Streambank_scour	3	0.05	0.00
Dairy	Disturbance free	Tunnel_gully	18	0.29	0.00
Dairy	Disturbance free	Intact	805	13.08	0.00
Total			**859**	**13.96**	**0.00**
Dairy	Land_Use	Cultivation	21	0.34	0.08
Dairy	Land_Use	Drains	31	0.50	0.02
Dairy	Land_Use	Earthworks	5	0.08	0.01
Dairy	Land_Use	Grazing	58	0.94	0.02
Dairy	Land_Use	Roads	14	0.23	0.02
Dairy	Land_Use	Tracks	511	8.30	0.60
Total			**640**	**10.40**	**0.74**
Dairy	Natural	Landslide	11	0.18	0.00
Dairy	Natural	Large_gully	1	0.02	0.00
Dairy	Natural	Open_gully	17	0.28	0.01
Dairy	Natural	Rockfall_or_barerock	13	0.21	0.01
Dairy	Natural	Sheetwash	1	0.02	0.00
Dairy	Natural	Streambank_deposition	4	0.06	0.01
Dairy	Natural	Streambank_scour	15	0.24	0.01
Dairy	Natural	Tunnel_gully	8	0.13	0.00
Dairy	Natural	Wind_erosion	1	0.02	0.00
Total			**71**	**1**	**0.04**
Drystock	Disturbance free	Debris_avalanche	1	0.02	0.00
Drystock	Disturbance free	Landslide	58	0.94	0.00
Drystock	Disturbance free	Open_gully	41	0.67	0.00
Drystock	Disturbance free	Slump_or_flow	20	0.32	0.00
Drystock	Disturbance free	Streambank_deposition	2	0.03	0.00
Drystock	Disturbance free	Streambank_scour	9	0.15	0.00
Drystock	Disturbance free	Tracks	1	0.02	0.00
Drystock	Disturbance free	Tunnel_gully	18	0.29	0.00
Drystock	Disturbance free	Intact	686	11.15	0.00
Total			**836**	**13.58**	
Drystock	Land_Use	Cultivation	7	0.11	0.05
Drystock	Land_Use	Drains	2	0.03	0.00
Drystock	Land_Use	Earthworks	8	0.13	0.01
Drystock	Land_Use	Grazing	53	0.86	0.02
Drystock	Land_Use	Harvest	5	0.08	0.00
Drystock	Land_Use	Roads	20	0.32	0.03
Drystock	Land_Use	Tracks	230	3.74	0.17
Total			**325**	**5.28**	**0.28**

Drystock	Natural	Landslide	111	1.80	0.04
Drystock	Natural	Large_gully	4	0.06	0.00
Drystock	Natural	Open_gully	77	1.25	0.03
Drystock	Natural	Rockfall_or_barerock	107	1.74	0.09
Drystock	Natural	Slump_or_flow	3	0.05	0.00
Drystock	Natural	Streambank_deposition	9	0.15	0.01
Drystock	Natural	Streambank_scour	11	0.18	0.00
Drystock	Natural	Tunnel_gully	21	0.34	0.01
Drystock	Natural	Wind_erosion	3	0.05	0.00
Total			**346**	**6**	**0.18**
Exotic_Scrub	Disturbance free	Open_gully	3	0.05	0.00
Exotic_Scrub	Disturbance free	Sheetwash	1	0.02	0.00
Exotic_Scrub	Disturbance free	Streambank_deposition	2	0.03	0.00
Exotic_Scrub	Disturbance free	Streambank_scour	3	0.05	0.00
Exotic_Scrub	Disturbance free	Tunnel_gully	1	0.02	0.00
Exotic_Scrub	Disturbance free	Intact	46	0.75	0.00
Total			**56**	**0.91**	**0.00**
Exotic_Scrub	Land_Use	Cultivation	1	0.02	0.00

Land-use class	Disturbance	Disturbance type	Number of points	points as % of regional total	bare soil as % of regions sample area
Exotic_Scrub	Land_Use	Grazing	1	0.02	0.00
Exotic_Scrub	Land_Use	Harvest	1	0.02	0.00
Exotic_Scrub	Land_Use	Roads	3	0.05	0.00
Exotic_Scrub	Land_Use	Tracks	22	0.36	0.02
Total			**28**	**0.45**	**0.02**
Exotic_Scrub	Natural	Debris_avalanche	1	0.02	0.00
Exotic_Scrub	Natural	Geothermal	3	0.05	0.01
Exotic_Scrub	Natural	Landslide	2	0.03	0.00
Exotic_Scrub	Natural	Open_gully	3	0.05	0.00
Exotic_Scrub	Natural	Rockfall_or_barerock	2	0.03	0.00
Exotic_Scrub	Natural	Streambank_deposition	2	0.03	0.00
Exotic_Scrub	Natural	Streambank_scour	2	0.03	0.00
Total			**15**	**0**	**0**
Hort	Disturbance free	Open_gully	1	0.02	0.00
Hort	Disturbance free	Intact	58	0.94	0.00
Total			**59**	**0.96**	**0.00**
Hort	Land_Use	Cultivation	14	0.23	0.09
Hort	Land_Use	Earthworks	1	0.02	0.00
Hort	Land_Use	Grazing	1	0.02	0.00
Hort	Land_Use	Harvest	3	0.05	0.00
Hort	Land_Use	Tracks	24	0.39	0.03
Total			**102**	**1.66**	**0.13**
Hort	Natural	Landslide	2	0.03	0.00
Hort	Natural	Rockfall_or_barerock	1	0.02	0.00
Total			**3**	**0**	**0.02**
Natural_Forest	Disturbance free	Debris_avalanche	69	1.12	0.00
Natural_Forest	Disturbance free	Landslide	26	0.42	0.00
Natural_Forest	Disturbance free	Large_gully	3	0.05	0.00
Natural_Forest	Disturbance free	Open_gully	11	0.18	0.00
Natural_Forest	Disturbance free	Rockfall_or_barerock	1	0.02	0.00

Land-use class	Disturbance	Disturbance type	Number of points	points as % of regional total	bare soil as % of regions sample area
Natural_Forest	Disturbance free	Streambank_deposition	1	0.02	0.00
Natural_Forest	Disturbance free	Streambank_scour	7	0.11	0.00
Natural_Forest	Disturbance free	Intact	699	11.36	0.00
Total			**817**	**13.27**	**0.00**
Natural_Forest	Land_Use	Grazing	2	0.03	0.00
Natural_Forest	Land_Use	Harvest	3	0.05	0.00
Natural_Forest	Land_Use	Roads	5	0.08	0.01
Natural_Forest	Land_Use	Tracks	22	0.36	0.01
Total			**32**	**0.52**	**0.02**
Natural_Forest	Natural	Debris_avalanche	1	0.02	0.00
Natural_Forest	Natural	Landslide	9	0.15	0.00
Natural_Forest	Natural	Large_gully	1	0.02	0.00
Natural_Forest	Natural	Open_gully	4	0.06	0.00
Natural_Forest	Natural	Rockfall_or_barerock	9	0.15	0.01
Natural_Forest	Natural	Streambank_deposition	14	0.23	0.01
Natural_Forest	Natural	Streambank_scour	5	0.08	0.00
Total			**43**	**0.70**	**0.03**
Natural_Scrub	Disturbance free	Debris_avalanche	21	0.34	0.00
Natural_Scrub	Disturbance free	Landslide	29	0.47	0.00
Natural_Scrub	Disturbance free	Large_gully	2	0.03	0.00
Natural_Scrub	Disturbance free	Open_gully	6	0.10	0.00
Natural_Scrub	Disturbance free	Rockfall_or_barerock	4	0.06	0.00
Natural_Scrub	Disturbance free	Sheetwash	1	0.02	0.00
Natural_Scrub	Disturbance free	Slope_failure	1	0.02	0.00
Natural_Scrub	Disturbance free	Slump_or_flow	1	0.02	0.00
Natural_Scrub	Disturbance free	Streambank_deposition	2	0.03	0.00
Natural_Scrub	Disturbance free	Streambank_scour	5	0.08	0.00
Natural_Scrub	Disturbance free	Tunnel_gully	3	0.05	0.00
Natural_Scrub	Disturbance free	Intact	425	6.90	0.00
Total			**500**	**8.12**	**0.00**
Natural_Scrub	Land_Use	Grazing	1	0.02	0.00
Natural_Scrub	Land_Use	Harvest	2	0.03	0.00
Natural_Scrub	Land_Use	Roads	6	0.10	0.01
Natural_Scrub	Land_Use	Tracks	46	0.75	0.03
Total			**55**	**0.89**	**0.03**
Natural_Scrub	Natural	Landslide	8	0.13	0.00
Natural_Scrub	Natural	Large_gully	1	0.02	0.00
Natural_Scrub	Natural	Debris_avalanche	4	0.06	0.00
Natural_Scrub	Natural	Open_gully	5	0.08	0.00
Natural_Scrub	Natural	Rockfall_or_barerock	10	0.16	0.01
Natural_Scrub	Natural	Streambank_deposition	8	0.13	0.01
Natural_Scrub	Natural	Streambank_scour	6	0.10	0.00
Total			**42**	**0.68**	**0.03**
Other (ED)	Disturbance free	Other (ED)	342	5.56	0.00
Total			**342**	**5.56**	**0.00**
Other (ED)	Land_Use	Cultivation	1	0.02	0.00
Other (ED)	Land_Use	Earthworks	13	0.21	0.08
Other (ED)	Land_Use	Grazing	2	0.03	0.00

Other (ED)	Land_Use	Harvest	1	0.02	0.00
Other (ED)	Land_Use	Roads	14	0.23	0.02
Other (ED)	Land_Use	Tracks	51	0.83	0.07
Total			**82**	**1**	**0.17**
Plantation	Disturbance free	Debris_avalanche	3	0.05	0.00
Plantation	Disturbance free	Landslide	11	0.18	0.00
Plantation	Disturbance free	Large_gully	1	0.02	0.00
Plantation	Disturbance free	Open_gully	6	0.10	0.00
Plantation	Disturbance free	Streambank_deposition	1	0.02	0.00
Plantation	Disturbance free	Streambank_scour	2	0.03	0.00
Plantation	Disturbance free	Tunnel_gully	1	0.02	0.00
Plantation	Disturbance free	Intact	530	8.61	0.00
Total			**555**	**9.02**	**0.00**
Plantation	Land_Use	Drains	1	0.02	0.00
Plantation	Land_Use	Earthworks	4	0.06	0.00
Plantation	Land_Use	Harvest	51	0.83	0.05
Plantation	Land_Use	Roads	19	0.31	0.02
Plantation	Land_Use	Tracks	96	1.56	0.10
Total			**171**	**2.78**	**0.17**
Plantation	Natural	Landslide	10	0.16	0.00
Plantation	Natural	Large_gully	1	0.02	0.00
Plantation	Natural	Open_gully	4	0.06	0.00
Plantation	Natural	Rockfall_or_barerock	6	0.10	0.00
Plantation	Natural	Streambank_deposition	3	0.05	0.00
Plantation	Natural	Streambank_scour	4	0.06	0.00
Total			**28**	**0.45**	**0.01**
Tussock_Mntn	Disturbance free	Debris_avalanche	3	0.05	0.00
Tussock_Mntn	Disturbance free	Landslide	2	0.03	0.00
Tussock_Mntn	Disturbance free	Open_gully	3	0.05	0.00
Tussock_Mntn	Disturbance free	Rockfall_or_barerock	2	0.03	0.00
Tussock_Mntn	Disturbance free	Sheetwash	6	0.10	0.00
Tussock_Mntn	Disturbance free	Streambank_scour	3	0.05	0.00
Tussock_Mntn	Disturbance free	Tunnel_gully	7	0.11	0.00
Tussock_Mntn	Disturbance free	Intact	39	0.63	0.00
Total			**65**	**1.06**	**0.00**
Tussock_Mntn	Land_Use	Tracks	1	0.02	0.00
Total			**1**	**0.02**	**0.00**
Tussock_Mntn	Natural	Debris_avalanche	3	0.05	0.01
Tussock_Mntn	Natural	Landslide	1	0.02	0.00
Tussock_Mntn	Natural	Large_gully	1	0.02	0.01
Tussock_Mntn	Natural	Rockfall_or_barerock	15	0.24	0.14
Tussock_Mntn	Natural	Sheetwash	22	0.36	0.10
Tussock_Mntn	Natural	Streambank_deposition	2	0.03	0.00
Tussock_Mntn	Natural	Streambank_scour	3	0.05	0.02
Total			**47**	**0.76**	**0.28**
Wetland_Coastal	Disturbance free	Open_gully	1	0.02	0.00
Wetland_Coastal	Disturbance free	Streambank_deposition	1	0.02	0.00
Wetland_Coastal	Disturbance free	Intact	44	0.71	0.00
Total			**46**	**0.75**	**0.00**
Wetland_Coastal	Land_Use	Cultivation	1	0.02	0.00
Wetland_Coastal	Land_Use	Tracks	4	0.06	0.00
Total			**5**	**0.08**	**0.00**
Land-use class	**Disturbance**	**Disturbance type**	**Number of points**	**points as % of regional total**	**bare soil as % of regions sample area**
Wetland_Coastal	Natural	Landslide	1	0.02	0.00
Wetland_Coastal	Natural	Wind_erosion	4	0.06	0.02
Total			**5**	**0.08**	**0.02**

Table A2- 13: Change in coverage of freshly disturbed soil due to land-use disturbance, aggregated by land-use type

Disturbance	n	BS Area†	95% CI‡	n	BS Area+	95% CI‡	n	BS Area+	95% CI‡	Change		
		2007			2012			2017		2007-2017	2007-2012	2012-2017
Dairy	611	8.14	0.86	613	6.16	0.54	629	7.12	0.54	-	*	*
Drystock	438	5.84	0.72	398	4.06	0.55	310	5.33	1.01	*	*	*
Exotic_Scrub	33	8.27	4.31	34	6.18	2.05	26	4.50	1.25	-	-	-
Hort	73	42.08	8.84	51	11.39	5.14	40	19.30	9.69	*	*	-
Natural_Forest	19	4.16	0.90	18	3.61	1.09	31	3.68	1.08	-	-	-
Natural_Scrub	40	4.73	0.91	51	3.92	0.81	54	3.87	0.77	-	-	-
Plantation	192	8.72	1.36	206	6.47	0.82	170	6.21	0.89	*	*	-
Tussock_Mntn	1	2.00	0.00	1	1.00	0.00	1	2.00	0.00	+	+	+
Wetland_Coastal	2	16.50	146.12	3	4.00	6.57	4	3.00	2.25	+	+	+

† Mean coverage (%) of bare soil across 1 ha sample grids
‡ 95% confidence interval about the mean
n Sample number
* Statistically significant difference at P = 0.05; - No statistically significant difference at P = 0.05

Table A2- 14: Change in coverage of freshly disturbed soil due to natural erosion processes, aggregated by land-use type

Disturbance	n	BS Area†	95% CI‡	n	BS Area +	95% CI‡	n	BS Area +	95% CI‡	Change		
	2007				2012			2017		2007-2017	2007-2012	2012-2017
Dairy	50	3.22	0.54	66	2.62	0.43	64	3.09	0.75	-	*	-
Drystock	224	4.28	0.92	274	2.95	0.34	316	3.20	0.41	*	*	-
Exotic_Scrub	21	6.43	2.31	21	5.33	2.50	15	6.20	3.40	-	-	-
Natural_Forest	29	3.79	1.20	46	4.07	1.45	41	3.71	1.30	-	-	-
Natural_Scrub	47	3.62	0.77	45	3.98	1.25	41	4.10	1.36	-	-	-
Plantation	30	3.40	0.74	23	4.35	4.33	22	2.36	1.04	*	-	-
Tussock_Mntn	46	18.46	7.05	52	10.92	5.40	47	37.28	11.28	*	*	*
Wetland_Coastal	4	43.50	73.16	5	30.80	49.67	5	29.80	42.12	-	*	-

† Mean coverage (%) of bare soil across 1 ha sample grids
‡ 95% confidence interval about the mean
n Sample number
* Statistically significant difference at P = 0.05; - No statistically significant difference at P = 0.05

Appendix 3 – Maps

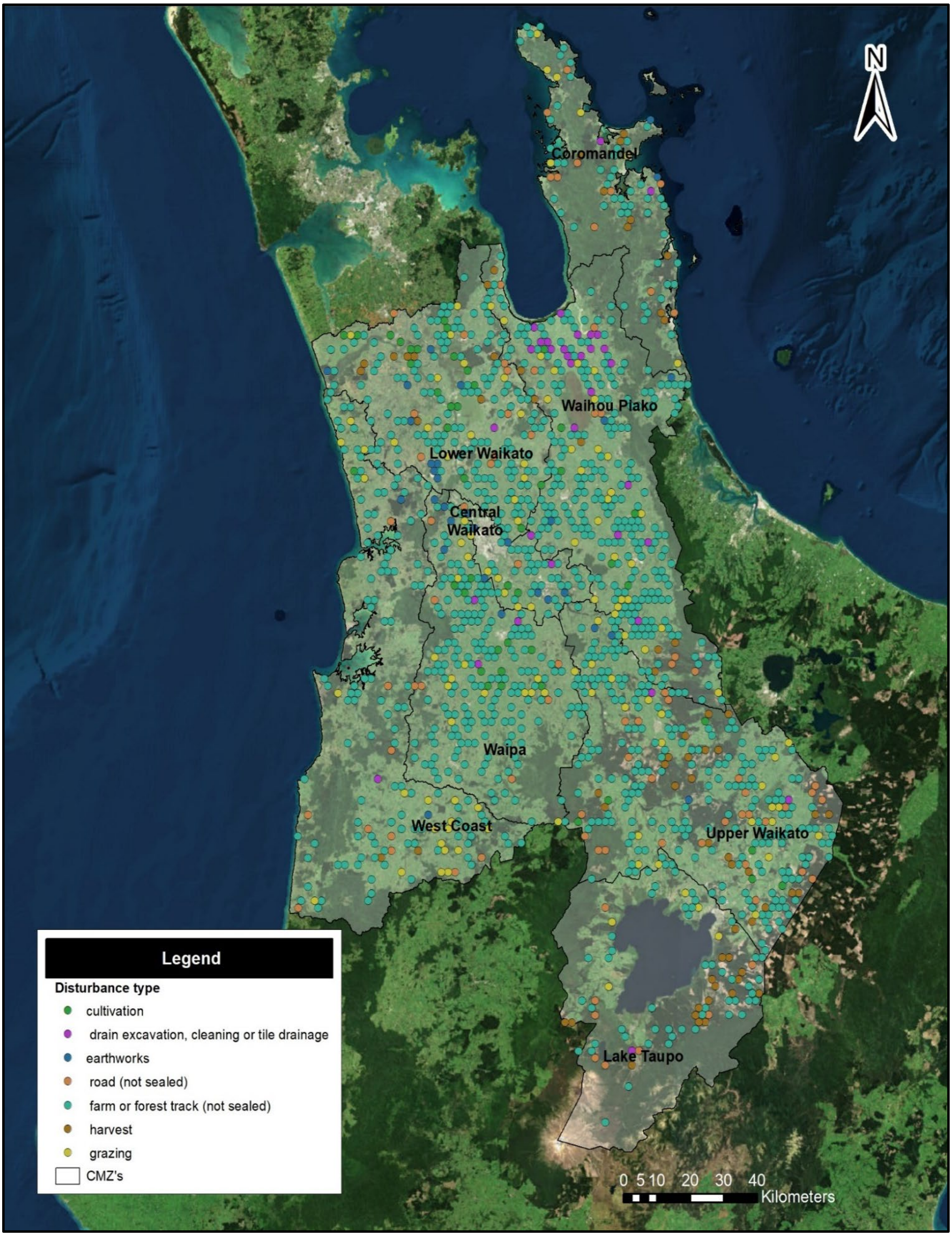

Figure A3- 1: Maps showing the location of points containing land-use disturbance for respective Catchment Management Zones (CMZs) in the Waikato region. Note that disturbance is defined as exposed soil on the land surface.

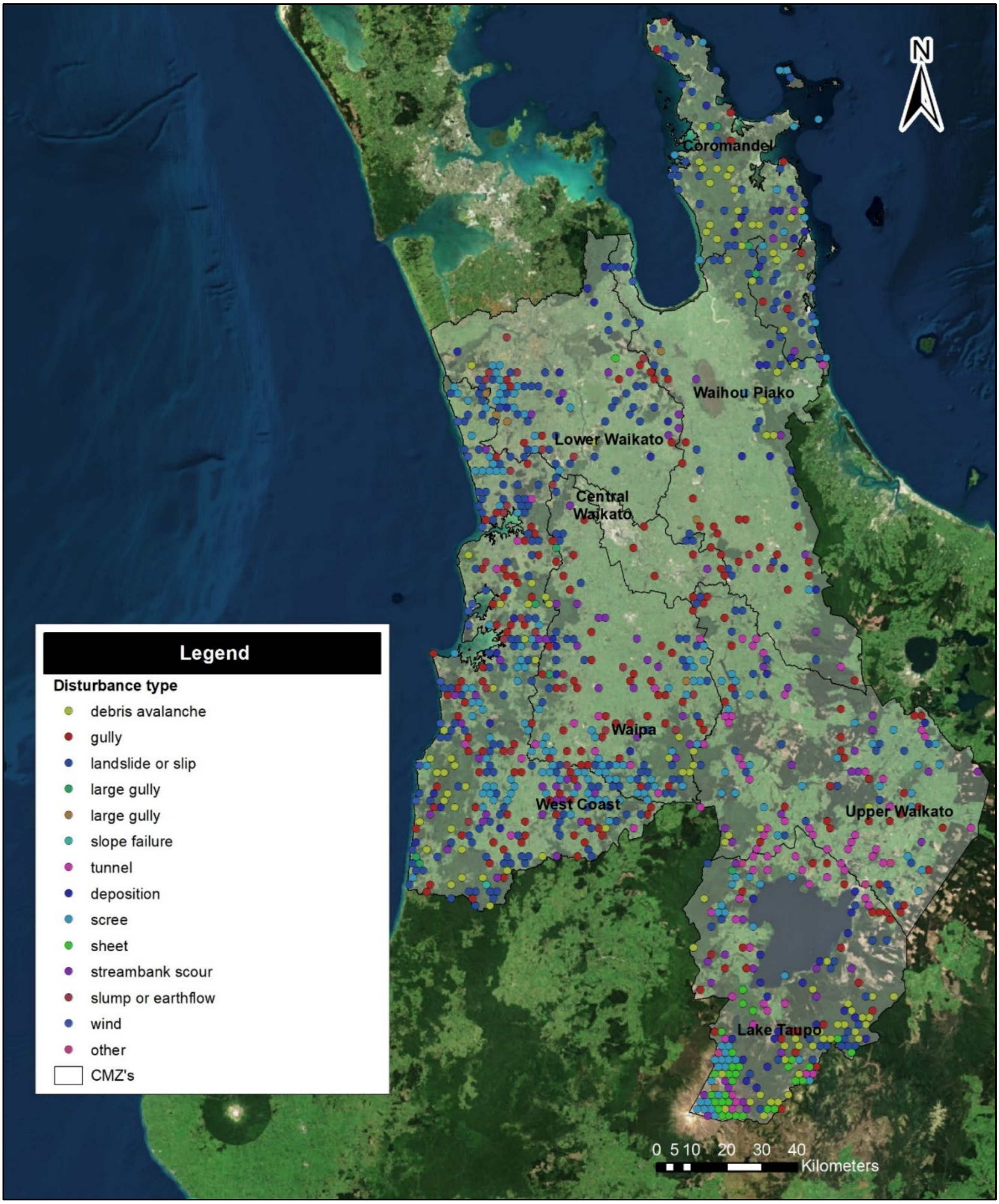

Figure A3- 2: Maps showing the location of points containing natural disturbance types for respective Catchment Management Zones (CMZs) in the Waikato region. Note that disturbance is defined as exposed soil on the land surface.