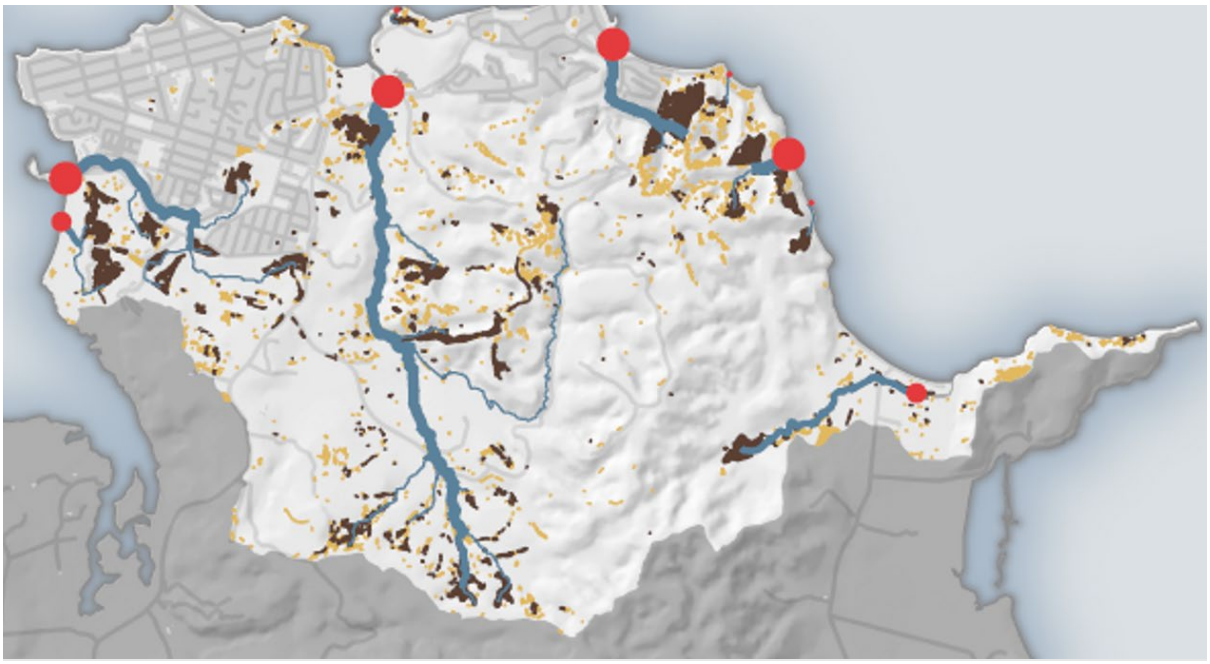
Mapping Bare Earth Areas
from
Cyclone Gabrielle 2023



Data Quality, Accuracy, and Development Report

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Image 1: Eels (tuna) are Important toanga (Photo credit: Zealandia 2022).

Executive Summary

This report documents a GIS analysis specifically developed to identify potential sediment sources, exposure, and deposition, caused by the 2023 Cyclone Gabrielle (Image 2), for five pilot catchments in the Auckland region. One of the key objectives of this pilot project was to utilise the generated Pre- and Post-Gabrielle Bare Earth Coverage to inform the development of planning, policy, and environmental initiatives, focused on sediment source and potential effects. This is required to improve the overall condition and quality of receiving aquatic environments and serves to meet multiple existing strategic requirements.

Additionally, the project aimed to create outputs that could be easily updatable and relevant to other key datasets (e.g. overland flow paths, rainfall, land parcels) and be able to provide several strategic uses to support near real-time management of natural systems and associated infrastructure, while providing a key guiding resource for policy planners.

In the Auckland region, Lynker Analytics (Lynker) has been refining a landcover classification for 2008, 2017, 2023 (imagery), using various aerial photographic formats and scales. This has informed the definition of "bare earth" for the purposes of this pilot study and the use of the outputs in strategic planning for the Auckland Region. Here, "*bare earth"* is defined as *"exposed soils, unconsolidated gravels or road materials, or sand, or deposited sediments, or sparsely vegetated ground, or tilled earth"*. These areas were defined and mapped from pre- and post-cyclone satellite imagery using imagery analysis techniques and machine learning.

This analysis also built upon previous work undertaken by Lynker in 2023. More specifically, Lynker developed the *Sediment Sources Rapid Identification and Management System* (SSRIMS) methodology. The SSRIMS was piloted on the Rodney region in 2023 and used the "bare earth coverage" to identify unsealed roads within high-risk environments (including proximity to bare-earth areas). Those identified areas could then be prioritised for management, through the Unsealed Roads Improvement Framework that Auckland Transport leads.

Key strategic benefits from this work include:

- Providing the geospatial stepping stones through high resolution aerial imagery analysis to classify areas of bare earth to help support a more cohesive, cost effective, and performance driven response to Regional Sediment Management.
- Generating Pre- and Post-Gabrielle Bare Earth Coverage to inform the development of planning, policy, and environmental initiatives, focused on sediment source and effects.
- Providing a "first cut" spatial plan for engagement with landowners, which serves to prioritise areas to improve the overall condition and quality of receiving environments by managing potential sediment runoff, slipping, and transport.
- Providing a Regional Coverage and a set of customisable GIS Tools to meet requirements set out in the National Policy Statement for Freshwater Management (NPS-FM).
- Applying these customisable GIS Tools to a) assess how effective management strategies were at increasing resilience to flooding and/or reducing/preventing erosion following significant weather events, and b) to form a strong base to test how fit for purpose future Action Plans are.

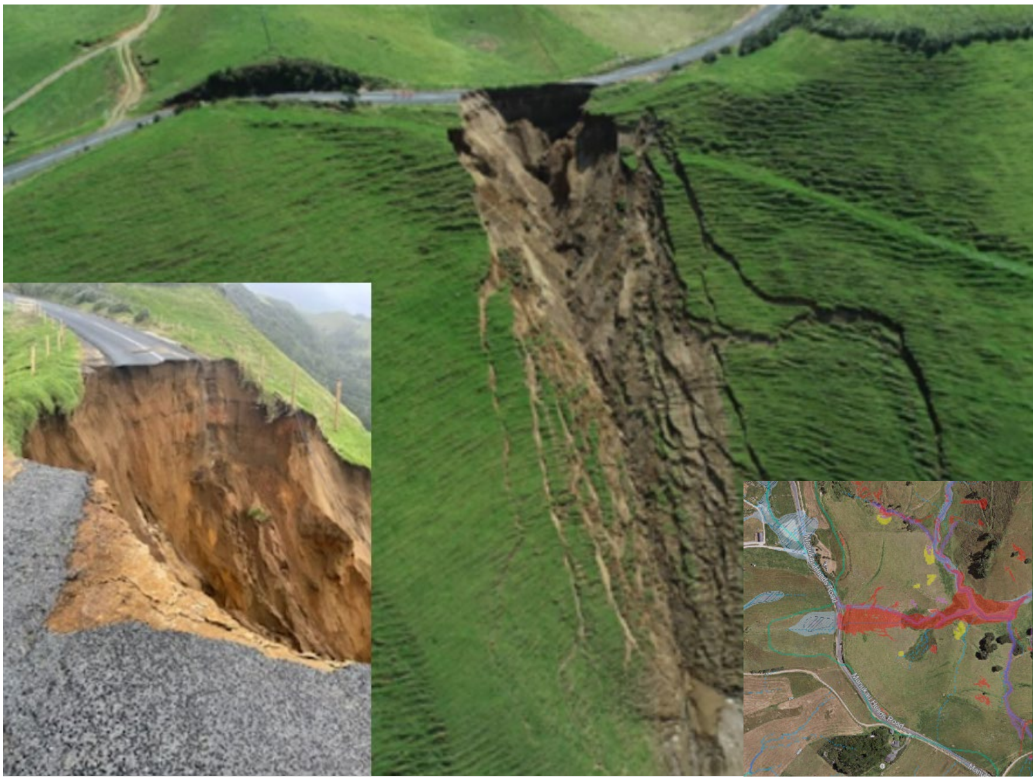

Image 2: Slip around Awhitu Peninsula in 2023 (Source: Stuff 2023).

Finally, a Web Map Viewer (Image 3) was created for the purposes of sharing the output data and information in spatial context. This includes bookmarks of locations within the study area that display high rates Bare Earth and other associated features interplaying such as land use cover, watercourses, and slope. The link to the viewer can be found here *Zealandia Sediment Sources Viewer 2024_Post Gabrielle Study*.

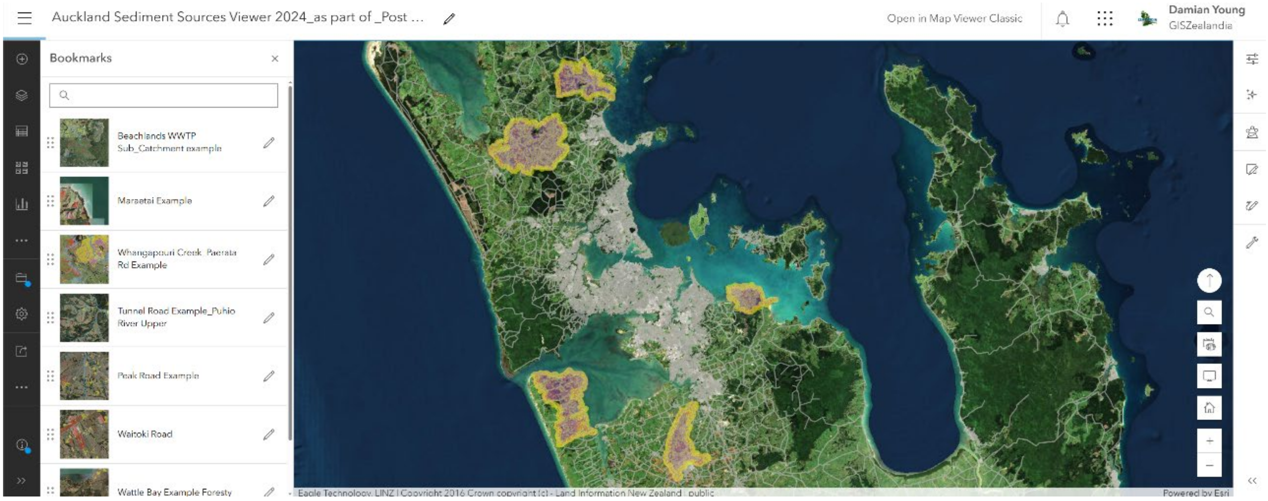

Image 3: Auckland Sediment Sources Viewer 2024

The spatial data can be used to enable engagement with key landowners, Tangata Whenua, and communities to support better practice in erosion and sediment control (e.g. afforestation of steep areas, riparian planting, etc.), focusing on high-risk areas.

1 Introduction

The 2020 National Policy Statement for Freshwater Management (NPS-FM), amended in January 2024 (MfE, 2024), sets the national direction for improving freshwater. Within the Auckland region, the Auckland Unitary Plan (Auckland Council, 2024) is scheduled to be revised to better reflect this national direction by 2027. This is complemented by the strategic direction set for the region in the Auckland Water Strategy (2022-2050; Auckland Council, 2022).

One of the issues in improving freshwater outcomes in the Auckland region is to control and reduce suspended sediments due to runoff. Suspended sediments entering waterways can cause adverse effects by increasing turbidity, reducing water clarity, and altering water chemistry (e.g. Ryan, 1991). These in turn can impact flora (e.g. Jones et al., 2012) and fauna (e.g. Cavanagh et al., 2014; Davis et al., 2022) within those waterways and in downstream receiving environments, including coastal and marine areas (Ellis et al., 2002; Lohrer et al., 2006). Increased levels of sediments can also result in the deposition and accumulation of mud on the seabed in these receiving environments and may change the character of the substrate (Ryan, 1991). Furthermore, in addition to having negative effects on significant ecological areas in depositional basins such as lakes, wetlands, and estuaries (e.g. Glade, 2003; Stephens et al., 2018), erosion and sedimentation can also affect Tangata Whenua (e.g. marae, pā sites), local communities (e.g. Modelling, 2019), and highly productive land. Impacts on the latter could lead to important economic losses and reduction in food supplies (Yates, 2023).

Auckland Council and Auckland Transport, in collaboration with Lynker Analytics Ltd and Zealandia Consulting Ltd, conducted a trial using high spatial and temporal resolution satellite imagery alongside new machine learning (ML) techniques to identify high priority unsealed rural roads requiring mitigation within the Rodney area. Mitigation (e.g. sealing) will help reduce sediments (here bare earth) from entering local waterways and/or significant ecological areas within the Rodney area (Young et al., 2024). The Rodney local board area was selected for the trial due to the high number of rural roads and other areas that discharge sediments into the Kaipara Harbour, which is a cause of concern (MfE, 2022).

Following the success of this trial, Auckland Council extended the analysis across the whole region. This extension assessed a total of 809 unsealed rural roads within the network to identify the 40 highest ranking roads for high sediment potential (Young et al., 2024). The information obtained from this modelling analysis provides the most robust assessment to date to assess potential areas of medium to high sediment discharges from unsealed rural roads. According to Reed and Scott (2024), this model has many valuable applications such as:

- Updating and upgrading of environmental assessment criteria and strengthening of assessment processes within management programmes.
- Identifying priority areas near unsealed roads for mitigation measures (e.g. installation of devices, design of new engineering solutions to channel water to designated treatment areas to trap sediments).
- Identifying priority areas near unsealed roads for mitigation measures (e.g. installation of devices, design of new engineering solutions to channel water to designated treatment areas to trap sediments).

Overall, easily updatable and relevant datasets (e.g. overland flow paths, rainfall) in combination with this modelling analysis can provide several strategic uses to support near real-time management of natural systems and associated infrastructure.

One strategic use of the modelling analysis mentioned above is the assessment of the effect(s) of an extreme weather event, such as a cyclone, on bare earth areas. In particular, modelling can assess areas with steep slopes that are intersected with an overland flow path and river networks (OLFP). This report, therefore, illustrates how such methodology could be applied to parts of the Auckland region following Cyclone Gabrielle, which impacted New Zealand between 11-17 February in 2023 (Gourley, 2023).

2 Objectives/Purpose

One of the primary objectives of this pilot study was to develop a GIS-based methodology to assess the effects of Cyclone Gabrielle on bare earth areas across five selected catchments within the Auckland region. These can act as sources of sediments, which can then enter local waterways via overland flow paths (OLFPs), piped and open channels, before eventually reaching the marine or freshwater receiving environment (e.g. lakes and wetlands). Affected areas can include Significant Ecological Areas (SEA) as defined in the Auckland Unitary Plan Operative (2024b). Lynker Analytics has been refining landcover classification, for 2008, 2017, 2023 (imagery), in the Auckland Region, using various aerial photographic formats and scales. This has informed the definition of bare earth for the purposes of this project analysis. Here, bare earth is defined as “exposed soils, unconsolidated gravels or road materials, or sand, or deposited sediments, or sparsely vegetated ground, or tilled earth”.

The development of planning, policy, and environmental initiatives, focused on sediment source and effects, is required to improve the overall condition and quality of receiving environments, and serves to meet multiple existing requirements. More specifically, this project sought to provide the geospatial stepping stones through high resolution aerial imagery analysis to classify areas that might be bare earth to help support a more cohesive, cost effective, and performance driven response to Regional Sediment Management.

The process to develop these geospatial stepping stones included the following:

- Obtaining Planet imagery for each selected catchment prior Cyclone Gabrielle and compare those to post-cyclone bare earth data derived from Maxar imagery (© Maxar Technologies).
- Identifying the following manually:
  - Potential sediment sources, exposure, and deposition, caused by Cyclone Gabrielle for five different catchments, by comparing Planet imagery to Maxar model of bare earth; and
  - The median slope for each bare earth feature.
- Analysing the following:
  - Calculating/estimating the sedimentation level caused by Cyclone Gabrielle sources only in comparison to all sources (as feasible).
  - Classifying bare earth in relation to area, slope classes, etc.
  - Running different scenarios on bare earth extent to predict the effects for changes in bare earth (e.g. slope, proximity to an OLFP, etc.). This could use some kind of explainable AI.
  - Running a visual model, a geometric network model, to predict the path of sediment-like material from bare earth areas to the marine environment.
- Presenting results by catchments in a series of maps.
- Presenting analytical statistics in a series of charts and tables.

2.1 Refinement Process

The GIS analysis required several steps, including iterations and improvements of the methodology to consider the data. A primary objective of the refinement process was to consider key questions that needed to be answered. Meetings with internal council stakeholder partners helped to align with their requirements, including covering the following:

- Land Title Coverage as a core reporting unit to support strategy and policy design.
- Existing policy, plan, and other provisions, which a bare earth geometry might be implemented in liaison with landowners and stakeholders.
- The multi-benefits of observing changes in near real-time and how that might be used to support erosion, sediment, and catchment soil conservation to achieve multiple current requirements/drivers i.e. Freshwater National Policy Statements (NPS-FM), Freshwater Farm Plans (FWFPs) or consent requirements.
- Using existing regional scale features (e.g. OLFP Geometry; Auckland Council) in the initial high-level analysis (e.g. intersects with OLFP to bare earth).
- A simple repeatable geospatial model that can inform strategic management, policy, and planning.
- Apply learnings from previous studies and reports including Rodney Bare Earth Study (Young et al., 2024) refer to Figure 1.

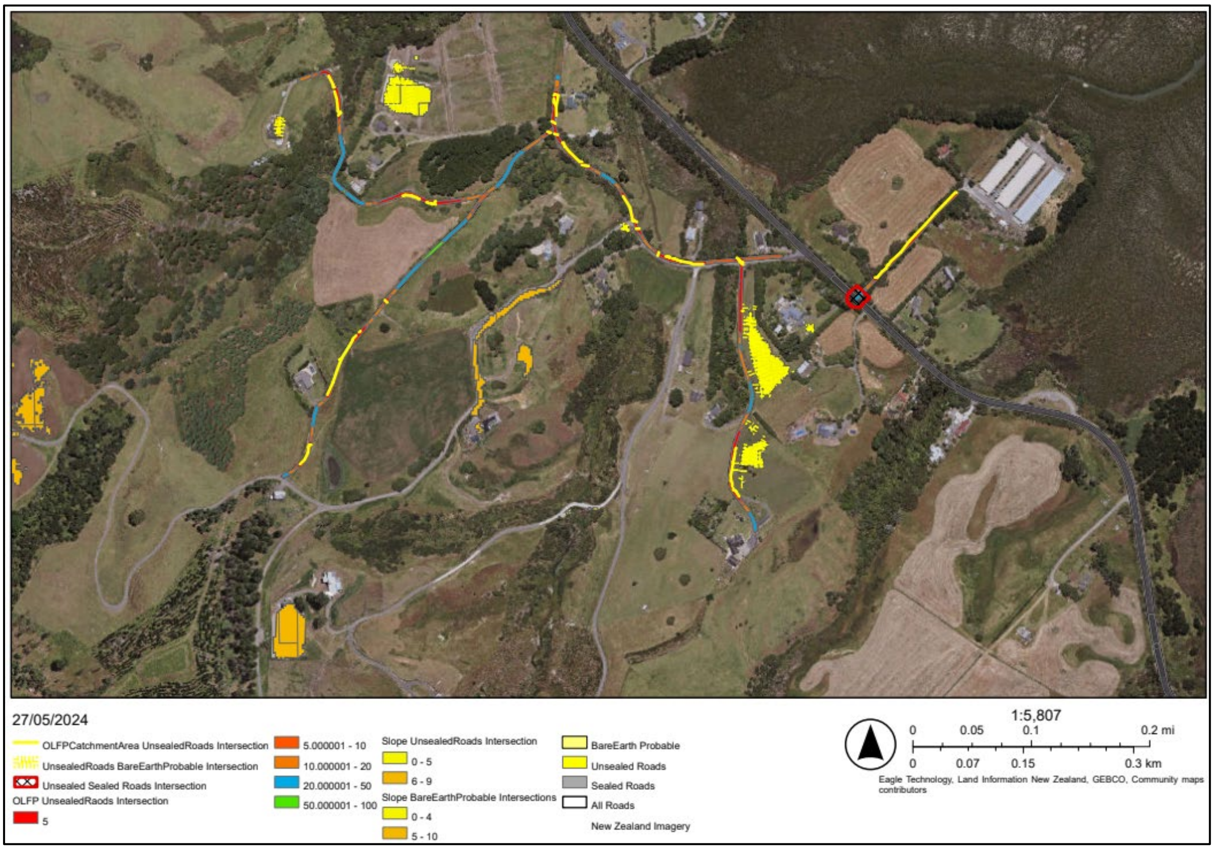

Figure 1: Excerpt from Rodney Bare Earth Study (Young et al., 2024) depicting Road Slope Classes and Bare Earth Areas.

3 Methodology

3.1 Study Area

The selection criteria to identify catchments for this study (Figure 2) involved the inclusion of diverse landscapes and land uses, occurrences of landslips, and the availability of imagery with relatively low cloud cover sourced from Maxar (© Maxar Technologies).

Figure 2: Five different catchments selected within the Auckland region.

3.2 Input Imagery

Post-cyclone bare earth areas had already been identified within the Auckland region (Young et al., 2024; Section 4.3). As a result, imagery (© Planet Labs PBC) taken prior to the cyclone was used to determine which bare earth areas were cyclone related within catchments deemed suitable for this pilot study (Figure 2).

Additionally, Maxar (© Maxar Technologies) 0.3m RGBI satellite imagery were obtained post-cyclone (March/April 2023) from Auckland Council. A cloud mask for the imagery was then manually created to remove cloud and cloud shadow areas from the output datasets.

3.3 Bare Earth Layer Creation and Processing

3.3.1 Post Gabrielle Bare Earth Identification

A Random Forest Machine Learning (ML) model was built to capture bare earth from satellite data (Maxar). Training data were captured in six specific areas (Figure 3). This ML model was previously applied to identify bare earth and unsealed roads across the Auckland region for the Auckland Council (Young et al., 2024). The detailed methodology for this model is described in Young et al. (2024; p. 7-8), which included conducting a training round using all four bands from the imagery.

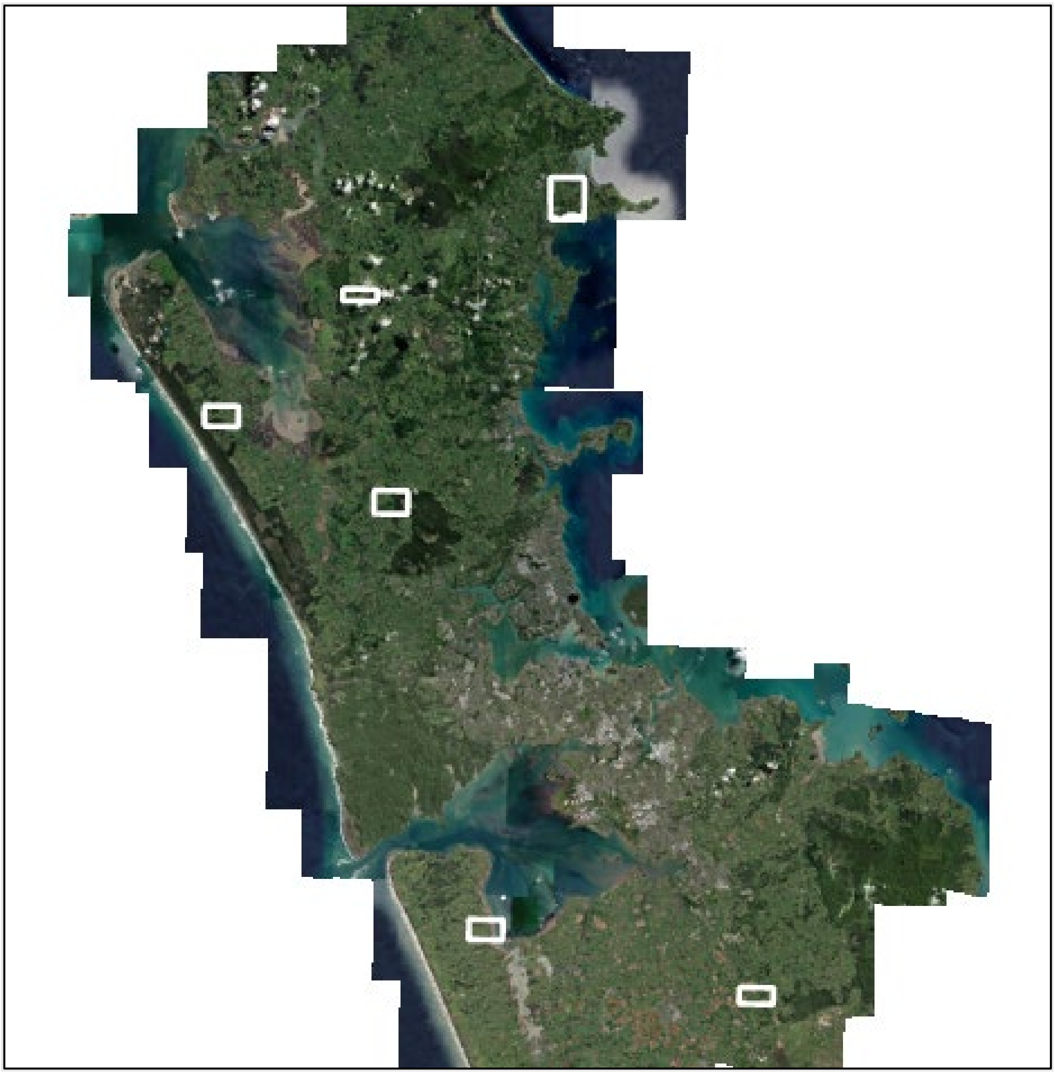

Figure 3: Training areas for the Machine Learning Model within the Auckland Region.

According to the authors, the feature importance indicates the relative contribution of each band towards assessing whether a pixel was deemed as bare earth or not. In this case, reflectance in the blue spectrum was the most important (Table 1).

Table 1: Feature importance of training bands.

Band	Feature importance
Band 1 importance (red)	0.182
Band 2 importance (green)	0.059
Band 3 importance (blue)	**0.617**
Band 4 importance (near infra-red)	0.141

Next, as detailed in Young et al. (2024; p. 7-8), inference of the whole Auckland region took place over 28 hours using 10 Amazon Web Services' EC2 Spot Instances. As part of this process, data were vectorised and small polygons (≤ $10m^2$) removed from the dataset. Following inference, a cloud mask was used to remove cloudy areas. During data processing, a further step was taken to remove false positives from the bare earth layer such as impervious surfaces (e.g. roads, buildings, and concreted areas) (Figure 4).

Figure 4: Inference output examples of bare earth, including false positives (bottom right panel).

Young et al. (2024; p. 8) further noted that “the bare earth layer created could more correctly be titled ‘bare earth” and “near bare earth”. Indeed, at times, areas on road edges, paddocks with thin brown grass, driveways, etc., were captured as bare earth. Further refinement of the bare earth geometry is possible (the data are considered sufficient to use for aggregate statistics and general analysis), and as new aerial imagery becomes available, updated bare earth mapping can be conducted”.

3.3.2 Pre-Gabrielle Bare Earth Identification

Planet data (© Planet Labs PBC) were ordered for the five catchments of interest with a capture date within one month prior and post-Cyclone Gabrielle event (11-17 February 2023), which included a national state of emergency being declared on 14th February 2023. A month later, all states of emergency were lifted (Gourley, 2023).

Planet satellite data have eight spectral bands within the optical to near infrared range making it very good at spectral identification of vegetation. However, this imagery is at a 3.7m (resampled to 3m) spatial resolution compared to the high-resolution satellite imagery from Maxar. It is, therefore, not appropriate for picking up small details. Nevertheless, the value of the Planet data is that they are highly available with each point on earth imaged approximately once per day. Furthermore, they are available at a relatively low cost, compared to higher resolution satellite imagery or aerial photography currently available on the market (e.g. Airbus Pleiades, Maxar).

From this Planet imagery, a bare earth layer was created by a ML model using python and scikit-learn open-source ML libraries (Figures 5-6). This is a similar process to the post-Cyclone Gabrielle bare earth layer. Several hundred examples of bare earth and "non-bare earth" were marked by a human annotator on the imagery.

Then, a ML model, i.e. the Random Forest model, was trained on these examples (Section 4.3.1.). The model was run on all the imagery with the result being a classified raster of bare earth. Finally, this raster was vectorised, ready for the next part of the analysis.

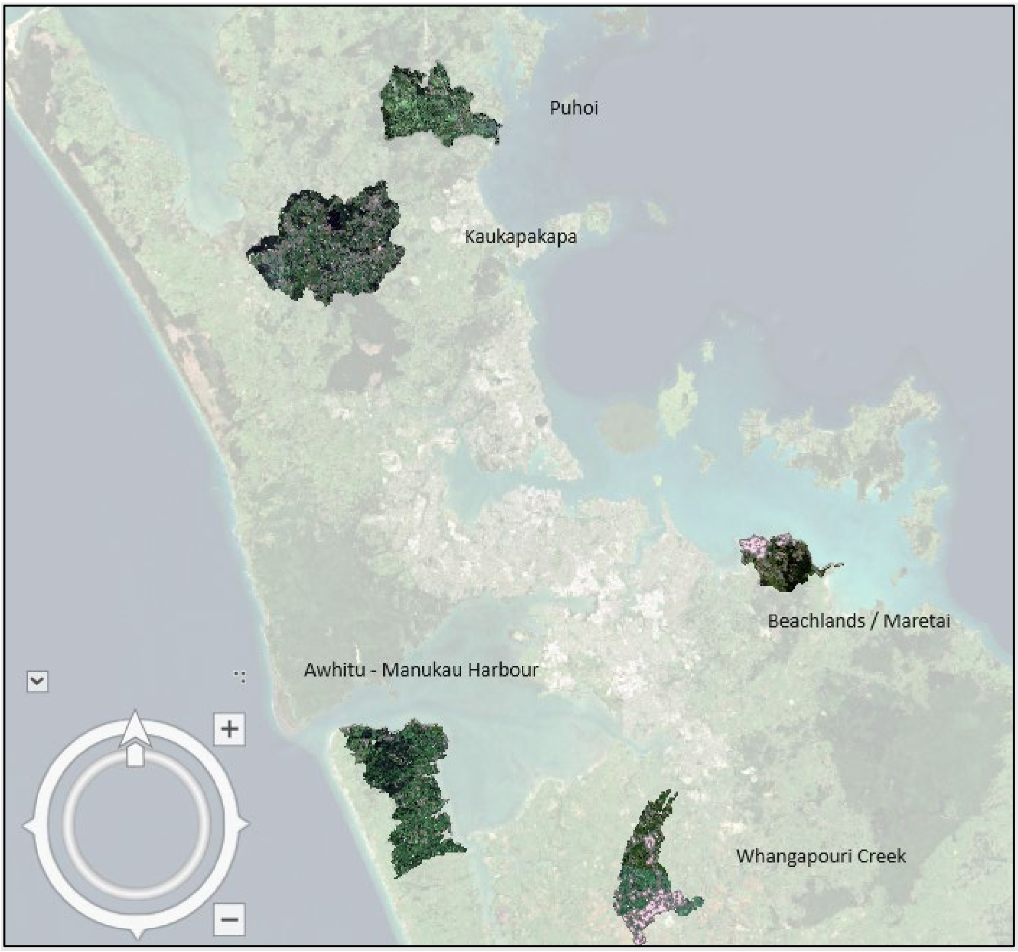

Figure 5: Planet Imagery (© Planet Labs PBC) over the selected catchment areas for this pilot study in the Auckland region. Note: overlaid in pink are the detected bare earth areas.

3.3.3 Impervious Surfaces

Previously known impervious surfaces (2017; Source: Lynker, 2022) were erased from the bare earth detections. Both ML models (i.e. ML model 1 and model 2) tend to have false positive detections on impervious surfaces. As a result, the 2017 impervious surface data were used to mask false positive bare earth detections (Figure 7).

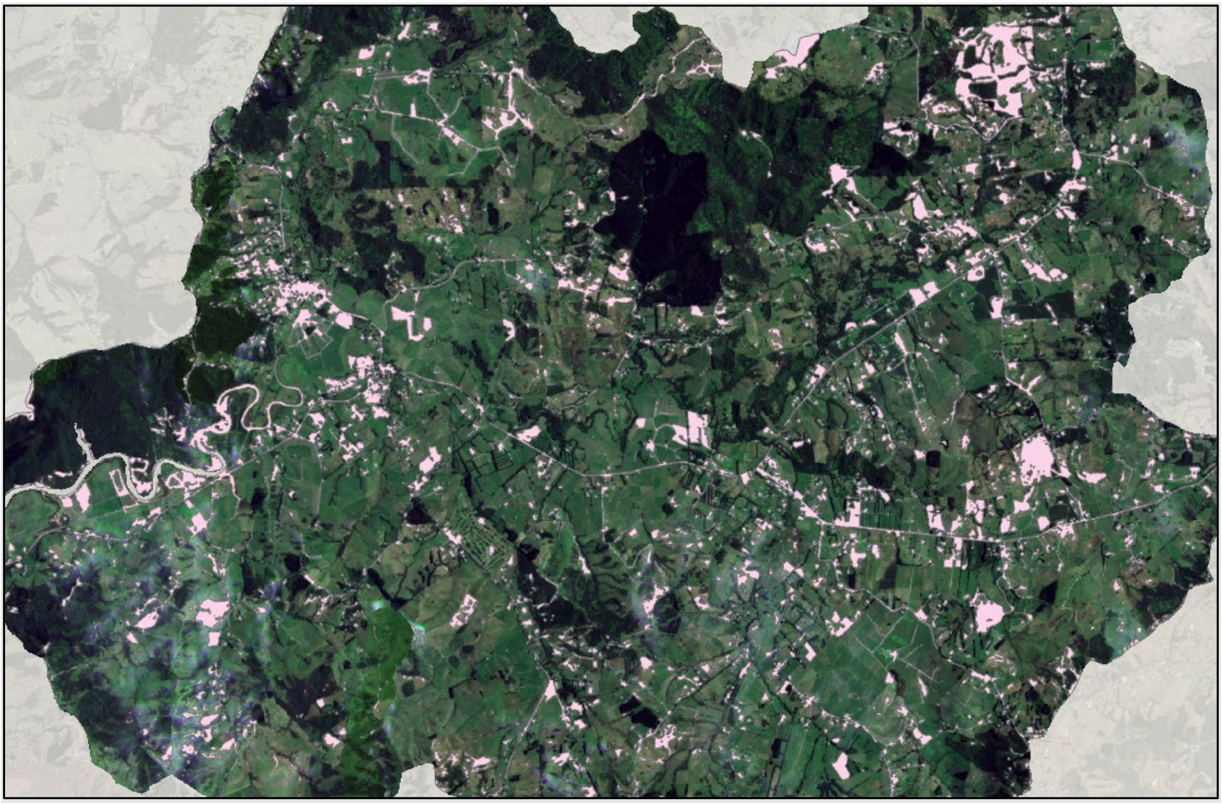

Figure 6: Zoomed in aerial view of Planet Imagery (© Planet Labs PBC) over the Kaukapakapa catchment. Overlaid in pink are the detected bare earth created by a Machine Learning model.

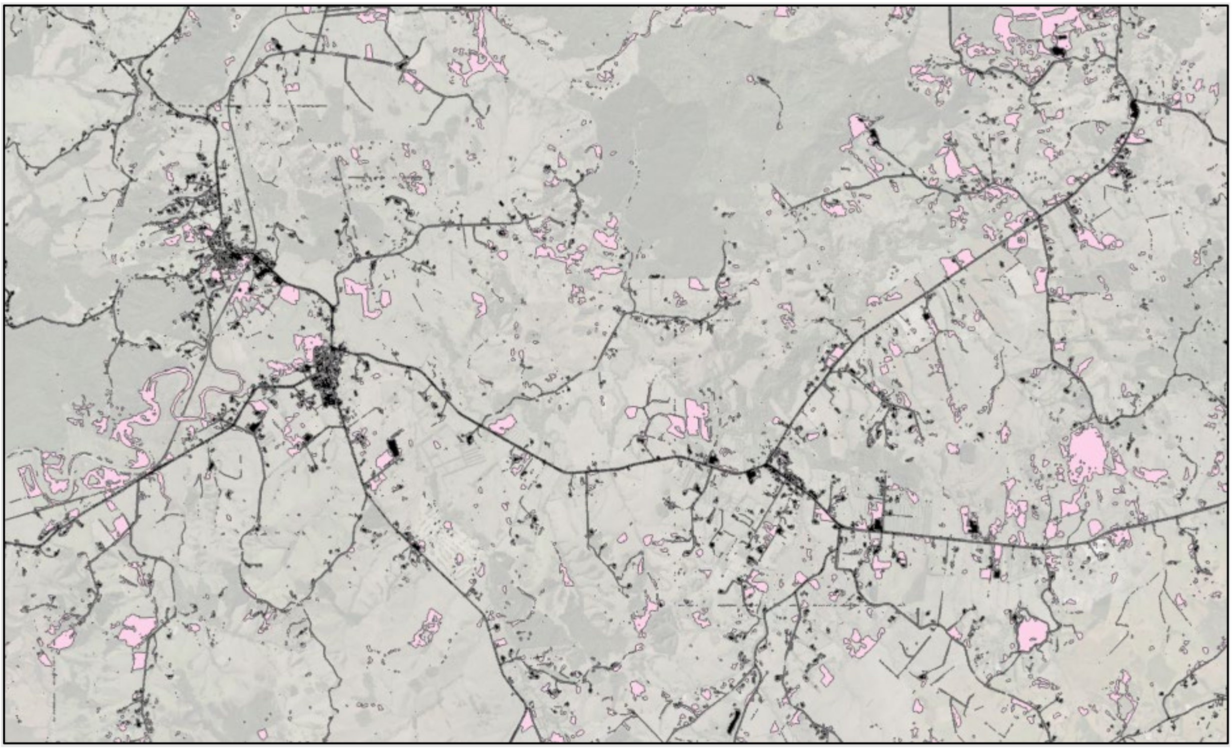

Figure 7: Example showing bare earth areas (pink polygons) and impervious surface (black polygons, 2017 data) created using Machine Learning models.

3.4 Cyclone Gabrielle Resulting Bare Earth Analysis/Identification/Conflation

Bare earth areas, that arose due to Cyclone Gabrielle, were detected through a geo-processing intersect analysis comparing the bare earth coverage before and after the event. Prior to this analysis, the following steps were taken:

- A field denoting either "before" or "after" the event was added to the polygons of bare earth in each layer, populated with either a 1 or a 0 accordingly.
- In the case where the bare earth detection models miss-classified, impervious surfaces, roads, and buildings were clipped from the bare earth layers.
- Any small polygons (< 50m^2) that remained were removed. This was conducted as a data smoothing exercise to reduce error noise and to consider a minimum threshold to better inform the likely management required.
- A polygon area of 50m^2 was selected because it is used as a reference area for land disturbance in the Auckland Unitary Plan Land Activity table (Auckland Council, 2024).

Next, the processed layers were combined, with “after Gabrielle” bare earth identified using the following calculations:

i. Where “before” + “after” = 1 and “before” = 1, then remove
ii. Were “before” + “after” = 2, then remove
iii. Where “before” + “after” = 1 and “after” = 1, then retain.

In summary, bare earth present before and bare earth present before and after (an overlap between layers) were removed (Figure 8) to create a new layer with only the new occurrences of bare earth post-Cyclone Gabrielle (Figure 9). Finally, some manual adjustments were made on the generated polygons to consolidate individual components, refine their edges, and eliminate any inaccuracies from the bare earth identification models that persisted after spatial clipping.

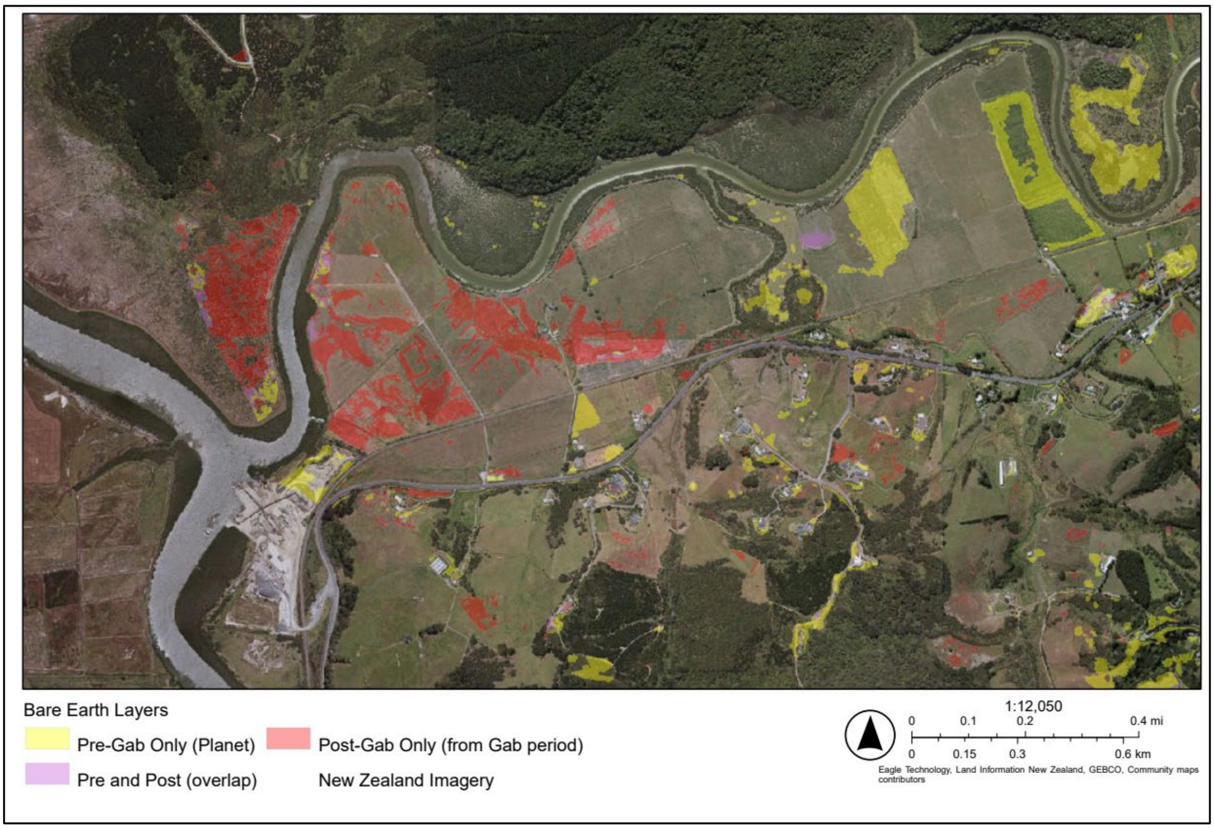

Figure 8: Example showing bare earth areas pre-, post-Cyclone Gabrielle, and areas of bare earth that persisted from pre- to post-cyclone within the Auckland region.

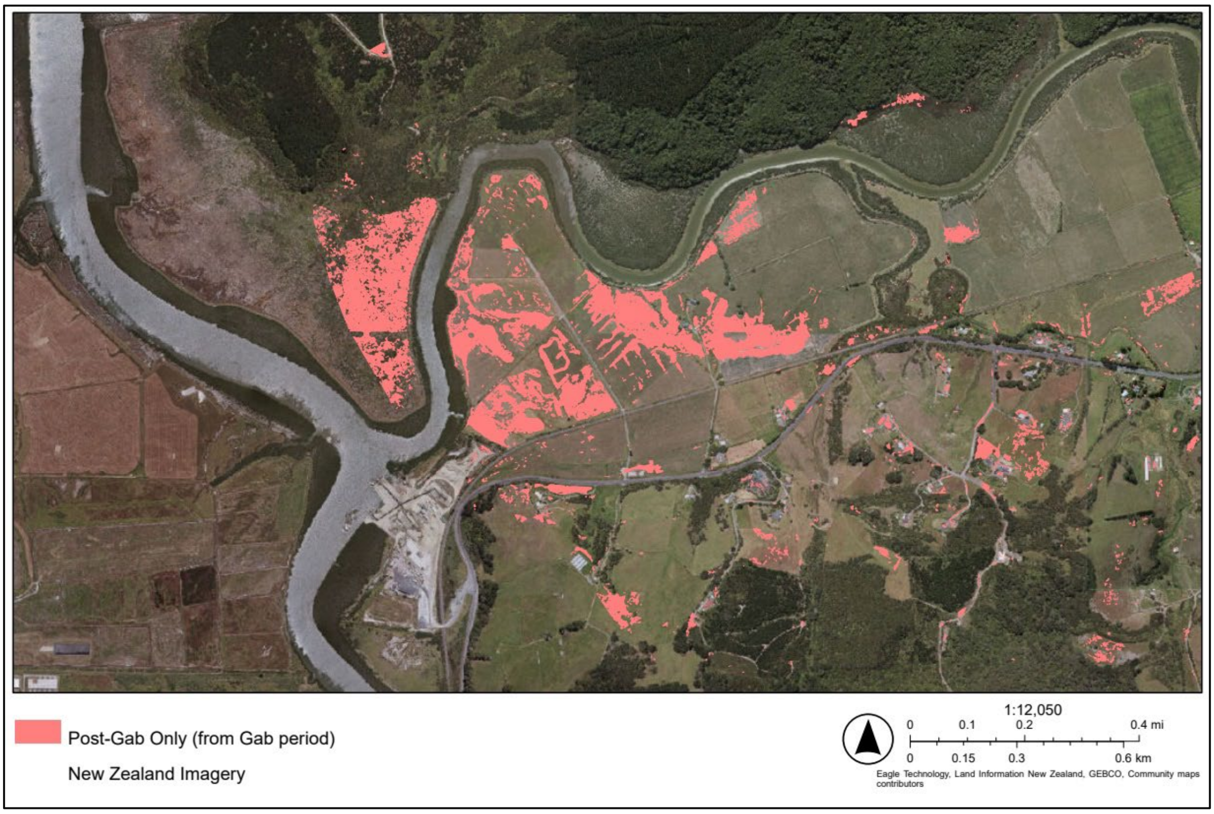

Figure 9: Example showing only bare earth areas that occurred post Cyclone Gabrielle within the Auckland region.

3.5 OLFP Bare Earth Intersect Reporting Tool

A geospatial linear network model was created to show the relative accumulation of sediments (per hectare) caused by bare earth due to Cyclone Gabrielle. The methodology used was as follows:

- Areas of post-cyclone bare earth were identified in the process described above (refer to part 4.4.) for each of the five catchments selected.
- Within these catchments, points where OLFP intercepted areas of bare earth were identified. A single point was then created for each individual intercept and assigned a weight of the area (ha) of bare earth that a OLFP crossed (Figure 10). These points are, from here on in, referred to as the predicted source.
- For each catchment, an OLFP geometric network model was also created to allow the tracing of sediments from predicted source to potential sink location. A potential sink point is defined here as a point where sediments might enter the coastal marine environment.
- For each predicted source point, the model was run to indicate the predicted path taken by source unconsolidated material from bare earth areas to an estuary or the sea (Figure 11).
- Both predicted paths and potential sinks were aggregated using the weightings (or area of the source bare earth). The aggregated weights were then used to create a schema showing relative predicted sources of post-cyclone sediment-like material.

Figure 10: Example illustrating the application of the OLFP Bare Earth Intersect Reporting Tool. Symbology: Bare earth areas not intersecting (yellow polygons) and intersecting (brown polygons) an overland flow path (OLFPs; blue lines) to a potential coastal sink (red circles).

Figure 11: Example of relative predicted accumulation of sediment-like material post-Cyclone Gabrielle from bare earth areas (brown polygons) intersecting directly with overland flow paths (OLFPs; orange lines) to a potential coastal sink (brown circles) before entering the coastal marine environment (blue polygon).
Note: the remaining OLFPs are symbolised by blue lines. (note this is not the CMA boundary but the terminus of the OLFP geometry).

3.6 Landslip Probability Analysis using Explainable AI

An Explainable AI model (refer to New Zealand AI Forum, 2023, for a review) was used in this "pilot study" to produce a landslip probability prediction over the five catchments selected. This model was developed using the interpretML machine learning library to provide a prediction of "landslip" and reveal the potential causative factors in "landslip" occurrence. Using the explainable AI model, it is then possible to examine the influence of the inputs to the model on the landslip probability prediction.

Here, the intersection of the post-cyclone bare earth, as discussed above (refer to section 4.5) and known landslip areas, from the latest GNS landslip database (as of 2024), were targeted. The Microsoft interpretML library was also used to provide interpretable predictions. Various inputs to the model were considered and are included in Table 2.

Table 2: Feature inputs to the Explainable AI model, including sources.

Feature	Source	Comment
Slope	Derived from the 1m DEM (2016)	
Aspect	Derived from the 1m DEM (2016)	
Vegetation (Tree) cover	An ML model run on the planet imagery for this project	Previous work has shown that land cover vegetation has an impact on landslide probability

3.6.1 Vegetation Map using Machine Learning

A ML model trained to identify vegetation landcover from Planet imagery was run on the pre-Cyclone Gabrielle imagery over the study area. This model identified the following tree cover categories: "Pine", "Hardwoods", and "Indigenous". The background vegetation cover over most of the catchment areas was grass/pasture or shallow rooting scrub. An example of this vegetation landcover prediction can be seen in Figure 12.

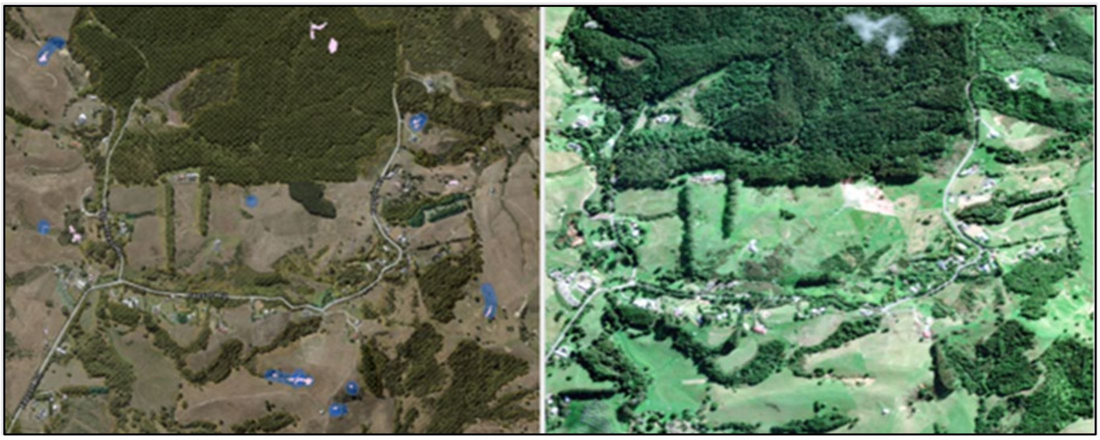

Figure 12: Predicted Tree cover. Left shows the predicted tree cover, and landslips on Planet imagery (© Planet Labs PBC). Right shows the post-Cyclone Gabrielle Maxar imagery (© Maxar Technologies) of the same area.

With this landcover model, we can identify the major areas of tree cover over the study areas at a time just before Cyclone Gabrielle event and in much greater spatial detail than is available from New Zealand Land Cover Database (LCDB, Manaaki Whenua-Landcare Research) or Land Use Cover Area Survey, New Zealand Land Use Map (LUCAS LUM, MfE) datasets.

3.6.2 Model Accuracy Assessment

The model evaluated 10m by 10m pixel sections of the landscape for landslip probability, without overlap. The example data used to train the model was randomly split into training and validation datasets. Outputs of the model are a probability raster, which is a type of spatial data layer used in geographic information systems (GIS) and remote sensing); examples are shown in Figure 13 and Figure 14.

We measured the accuracy of the model using the AUC metric. This metric was chosen as it evaluates the correctness of the ordering of predictions for a binary classification problem. The score given then summarises the discriminatory power of the model across various thresholds, providing insights into its overall predictive performance. The AUC scores for the “train” (0.871) and “validate” (0.854) models were 0.871 and 0.854, which indicated strong performance in the ordering of predictions.

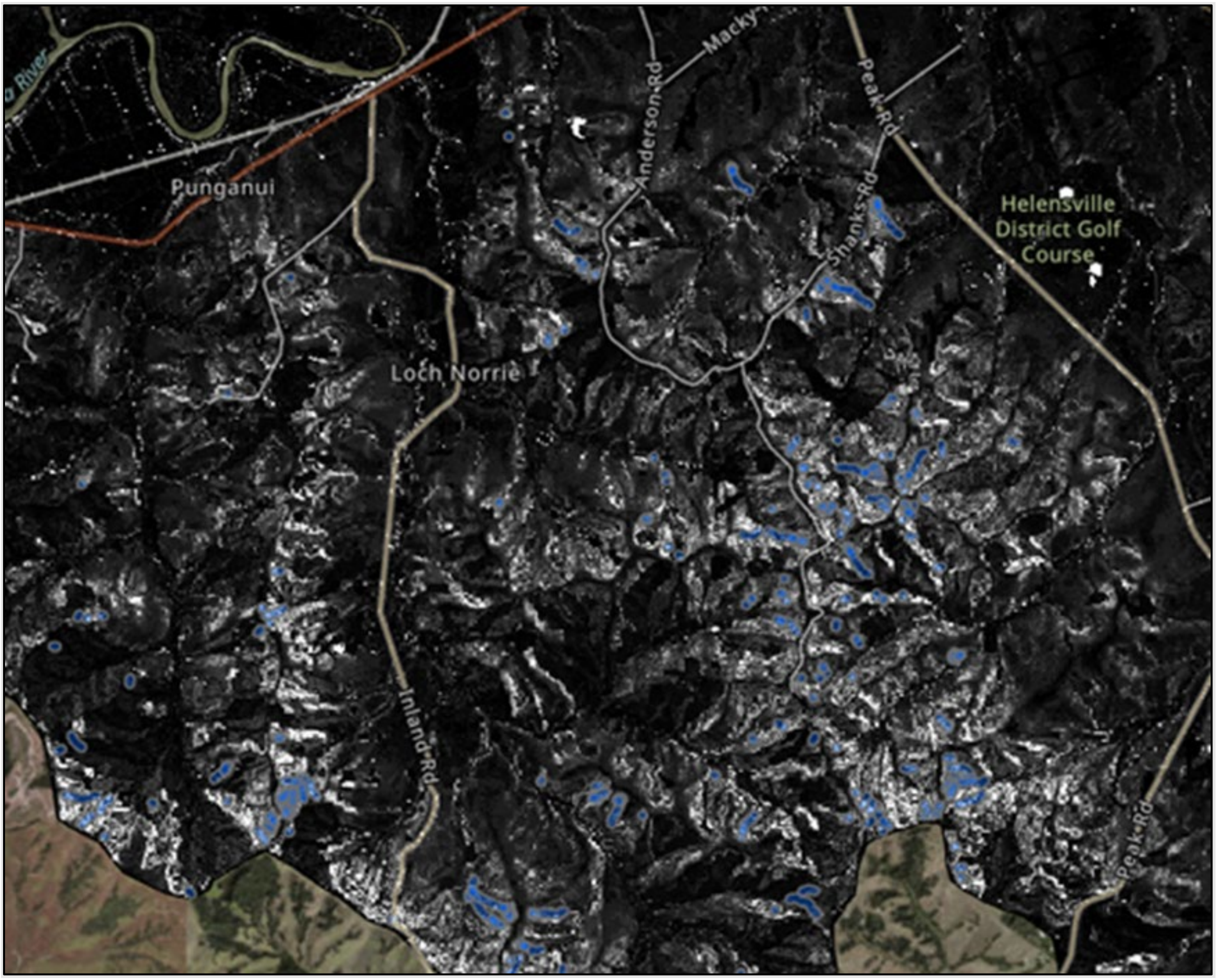

Figure 13: Probability of landslip layer, near Helensville, with GNS slip areas in blue.

Figure 14: Landslip probability layer for Beachlands/Maraetai catchment.

3.6.3 Explaining the Model Input Effects on Predictions and Results

The value of an interpretable model is a view of the influence of input variables on the output prediction. The influence of input variables was examined in the following figures to help explain the results.

Slope was clearly the biggest factor on bare earth/landslip likelihood; however, aspect had a big impact (Figure 15). This makes sense when considering the direction of wind and rain influencing the landslip likelihood, with North and North-East faces having greater exposure during the Cyclone Gabrielle event.

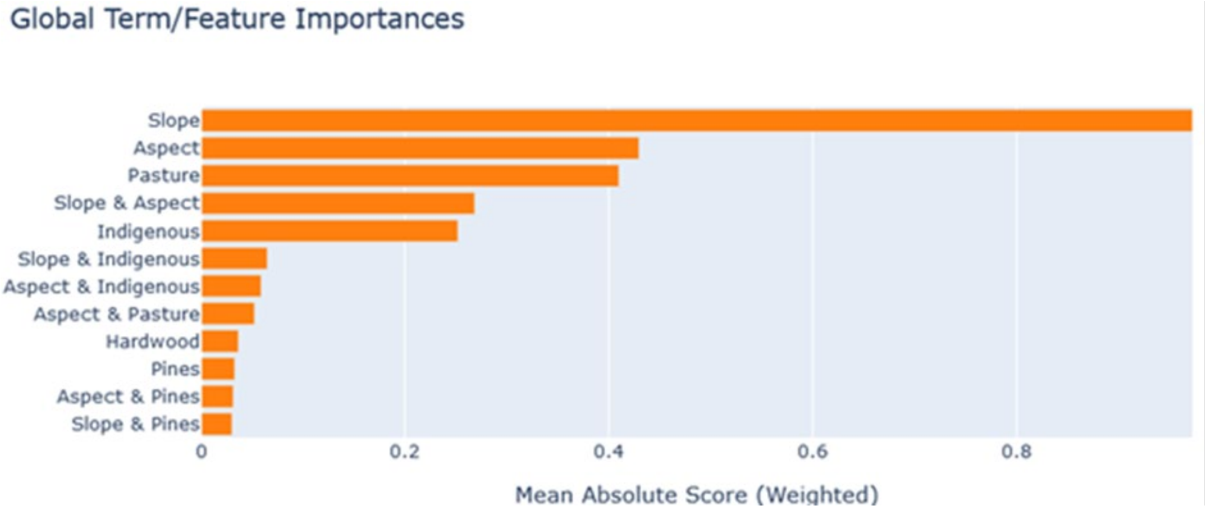

Figure 15: Feature importance of model inputs to landslip probability model.

The density indicates the frequency of the slope bands, and the score shows the likelihood of a slip for those values of slope. A score of 0 indicates no change of likelihood, negative scores indicate a reduced slip likelihood, while positive scores indicate an increased likelihood. A steady increase in slip likelihood from a 5 degree slope up to approximately 25 degrees was observed (Figure 16). It should be noted, however, that the plateau and reduction of slip likelihood seen for larger slope angles may not be a true effect as the quantity of data for these higher slope values was very low and so the training data for these cases were lacking.

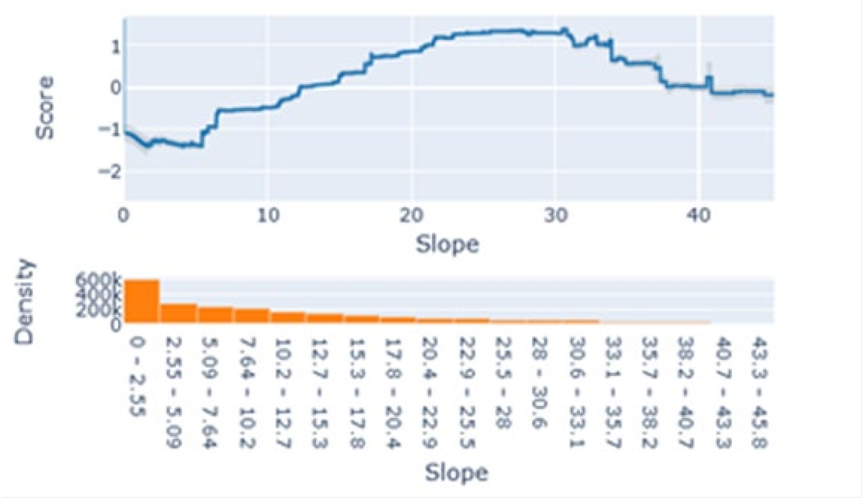

Figure 16: Likelihood of slip influence of slope.

An increased likelihood for North facing slopes (0 and 360 degrees) and a decreased likelihood for South facing slopes (180 degrees) were observed (Figure 17).

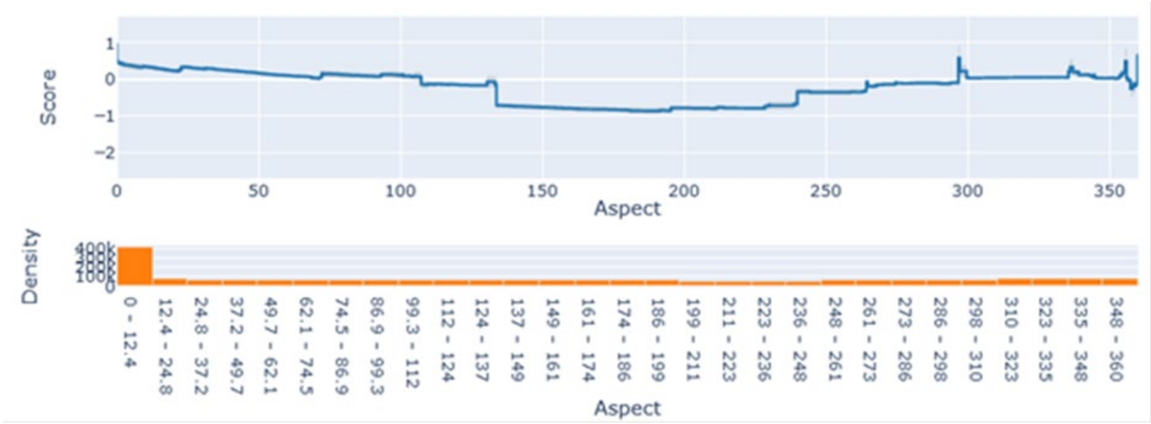

Figure 17: Likelihood of slip influence of slope aspect.

A strong protective effect (reduced likelihood) can be observed where the pasture value is 0, i.e. indicating not-pasture landcover (Figure 18). As the absence of pasture means the presence of tree cover, this indicates the protective effect of tree land cover.

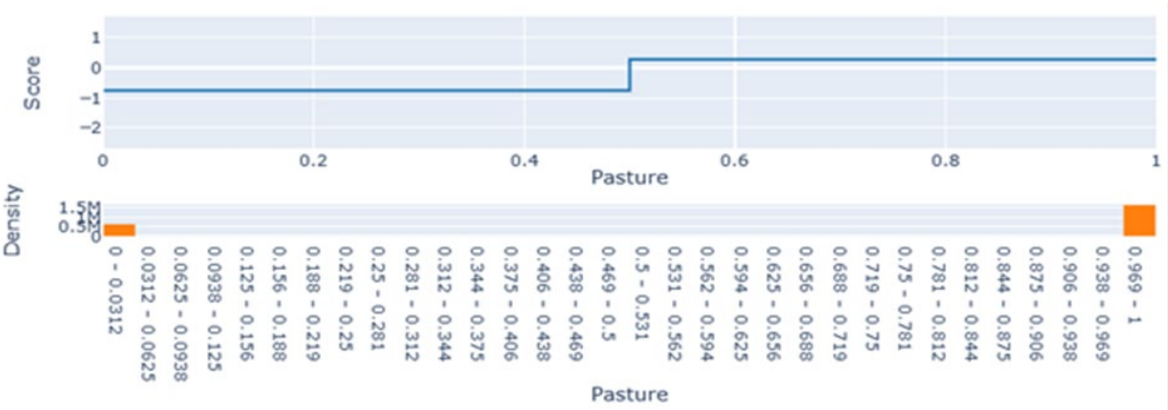

Figure 18: Likelihood of slip influence of pasture landcover.

Pine landcover was shown to have a modest effect (Figure 19). However, it should be noted that the absence of pasture (Figure 18), and this modest effect directly from pines is additive, and the true value of pines is protective.

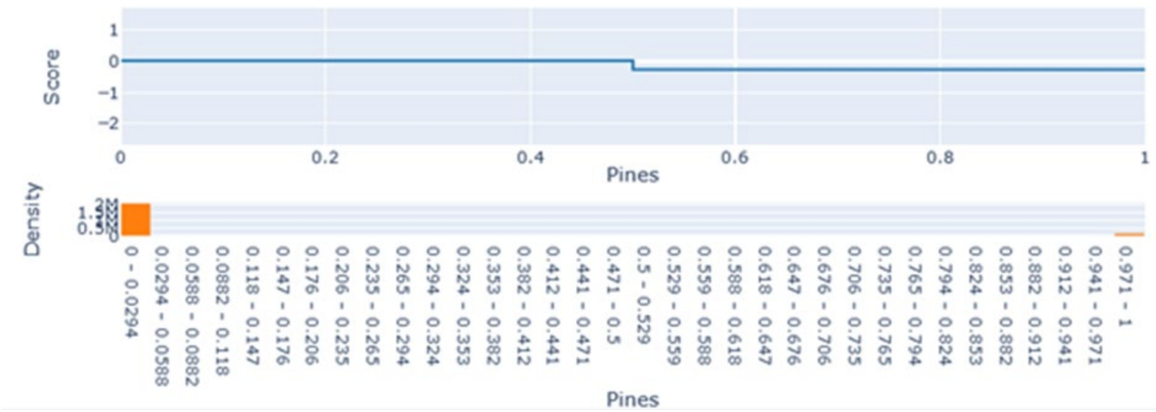

Figure 19: Likelihood of slip influence of pine landcover.

The model identified hardwood as strongly protective (Figure 20). However, there was very little training data for this class as compared to pine and pasture and while a protective effect was expected, the scale of the effect is uncertain without a larger study are including more training data.

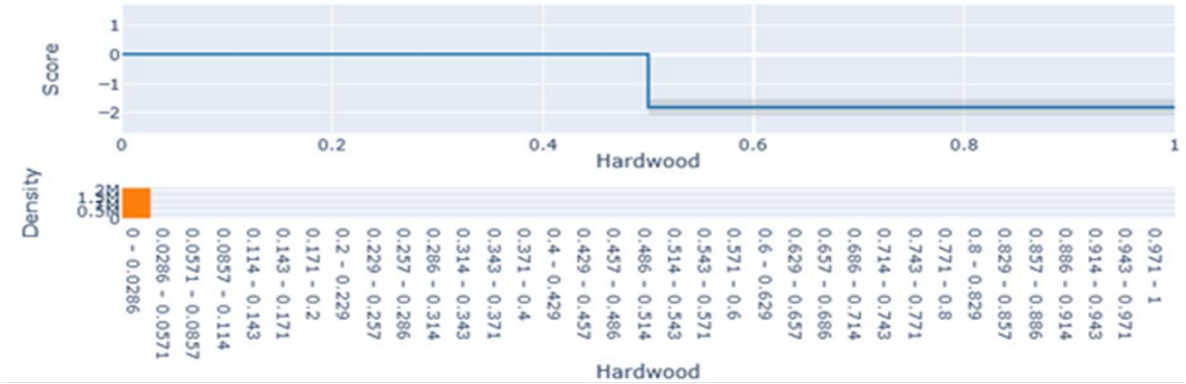

Figure 20: Likelihood of slip influence of Hardwood landcover.

Indigenous landcover is shown to have a strong protective effect (Figure 21).

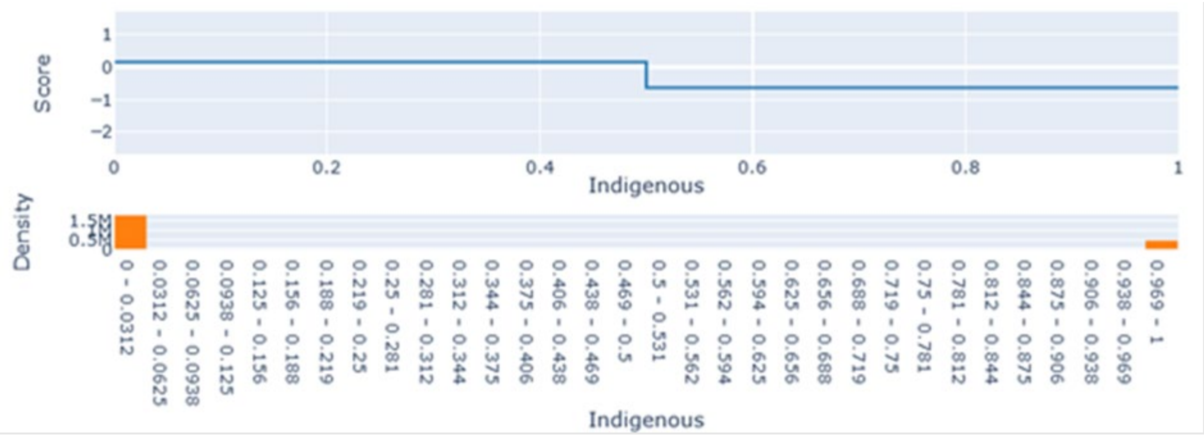

Figure 21: Likelihood of slip influence by indigenous forest landcover.

3.6.4 Future Work, Scenario Testing

With the trained explainable AI model, the impact on slip probability predictions of varying landcover could be identified. From this, it is possible to test planting plans and observe the model predictions with different land cover, particularly the impact of converting pasture to different types of vegetation. The model and methodology presented in this document pave the way for future work, exploring the effect on landslip probabilities with different vegetation types over landslip prone areas.

4 Results/Examples

4.1 Cyclone Gabrielle Resulting Bare Earth Analysis/Identification/Conflation

4.1.1 Overall Trends

Whangapouri Creek (10.7%) and Puhoi (2.2%) catchments had the highest and lowest percentages of bare earth within their respective catchment area (Table 3). When considering the steepness of the slope within these bare earth areas, then the Beachlands/Maraetai catchment (2.3%) and Kaukapakapa (0.3%) had the highest and lowest percentages (Table 3).

Table 3: Bare earth areas, including steep bare earth areas (ha) in relation to the total area (ha) for each catchment selected within the Auckland region. The highest percentages are highlighted in orange and the lowest in green.

CATCHMENT	Total catchment area	Total bare earth area (ha)	Percentage of bare earth area	Total steep bare earth area (ha)	Percentage of steep bare earth
KAUKAPAKAPA	11,843	309.2	2.6	365.9	0.3
AWHITU - MANUKAU HARBOUR	8,726	318.7	3.7	102.2	1.2
WHANGAPOURI CREEK	5,270	564.2	10.7	189.7	0.4
PUHOI	5,210	127.4	2.2	691.5	1.2
BEACHLANDS/MARAETAI	2,823	165.0	5.9	639.6	2.3

When comparing bare earth areas pre- and post-Cyclone Gabrielle, the highest percentage change occurred primarily within the Awhitu-Manukau Harbour catchment. In contrast, the highest percentage decreases occurred within the Puhoi catchment (Table 4).

Figures 22, 24, 26, 28, and 30 show the distribution of bare earth across the five pilot catchments within the Auckland region together with the areas identified across slope classes. Areas of bare earth by slope pre- vs post-cyclone indicate that there is no common pattern to all catchments, highlighting the need to conduct geo-spatial analysis per catchment within the region. Indeed, bare earth areas were widespread in some catchments (e.g. Kaukapakapa: Figure 24; Whangapouri Creek: Figure 30), while in others, these areas were concentrated in specific areas (e.g. Puhoi: Figure 22; North-east of Awhitu-Manukau Harbour: Figure 28). This variation could reflect land use within the different catchments. For example, horticulture crops are more prevalent in the Whangapouri Creek catchment than in the Awhitu and Puhoi catchments.

Higher rates of erosion were also apparent post-Cyclone Gabrielle in most slope classes (e.g. Kaukapakapa: Figure 24; Beachlands/Maraetai: Figure 26). Furthermore, bare earth areas with higher slopes had the tendency to be more heavily impacted (e.g. Puhoi: Figure 22). Steeper grazed coastal land and hilltop country with little vegetation cover also had greater bare earth extents in the Beachlands/Maraetai catchment for example (Figure 26). It should be noted that some of the areas of bare earth in the lower slope classes of some pilot catchments (e.g. Kaukapakapa: Figure 24) were highly likely to be flood plain entrained sediments deposited post-cyclone (as observed in the post event aerial photography).

While there was considerably more exposed bare earth following Cyclone Gabrielle (e.g. Awhitu-Manukau Harbour: Figure 28), in the Whangapouri Catchment (Figure 30), for example, rates of sedimentation were higher pre-cyclone, suggesting crop rotation and tilling activity is typical in this area. High rainfall intensity events and cyclones can cause significant soil erosion and damage agricultural lands. One soil conservation strategy to reduce erosion, better protect, and improve soil health is cover crops (Adetunji et al., 2020). This practice is used in New Zealand, including post-cyclone, and could, therefore, also explain higher rates of sedimentation pre-cyclone in some catchments of the Auckland region.

Table 4: Comparison of bare earth areas (ha) pre- and post-Cyclone Gabrielle by catchment and slope class. Table showing only the five highest percentage increases and decreases. The whole table is available in Appendix 1.

Catchment area	Slope class	Total bare earth (ha)	bare earth (ha) pre-cyclone	Percentage of total bare earth area pre-cyclone	bare earth (ha) post-cyclone	Percentage of total bare earth area post-cyclone	Percentage	Change
WHANGAPOURI CREEK (5,270 Ha)	26—35°	2.9	0.1	2.3	2.8	97.70	4,107	increase
AWHITU - MANUKAU HARBOUR (8,726 Ha)	0—3°	46	1.3	2.9	44.7	97.10	3,295	increase
AWHITU - MANUKAU HARBOUR (8,726 Ha)	16—20°	20.3	0.7	3.3	19.7	96.70	2,819	increase
AWHITU - MANUKAU HARBOUR (8,726 Ha)	4—7°	36.7	1.8	4.9	34.9	95.10	1,859	increase
AWHITU - MANUKAU HARBOUR (8,726 Ha)	8—15°	54.6	3.2	5.8	51.4	94.20	1,510	increase
WHANGAPOURI CREEK (5,270 Ha)	0—3°	315.4	178	56.4	137.4	43.60	23	decrease
PUHOI (5,210 Ha)	> 35°	10.3	6.3	61.6	3.9	38.40	38	decrease
PUHOI (5,210 Ha)	8—15°	16.3	11.3	69.7	4.9	30.30	57	decrease
PUHOI (5,210 Ha)	0—3°	7.5	6	79.6	1.5	20.40	74	decrease
PUHOI (5,210 Ha)	4—7°	13.8	11.3	81.6	2.5	18.40	78	decrease

4.1.2 Puhoi Catchment

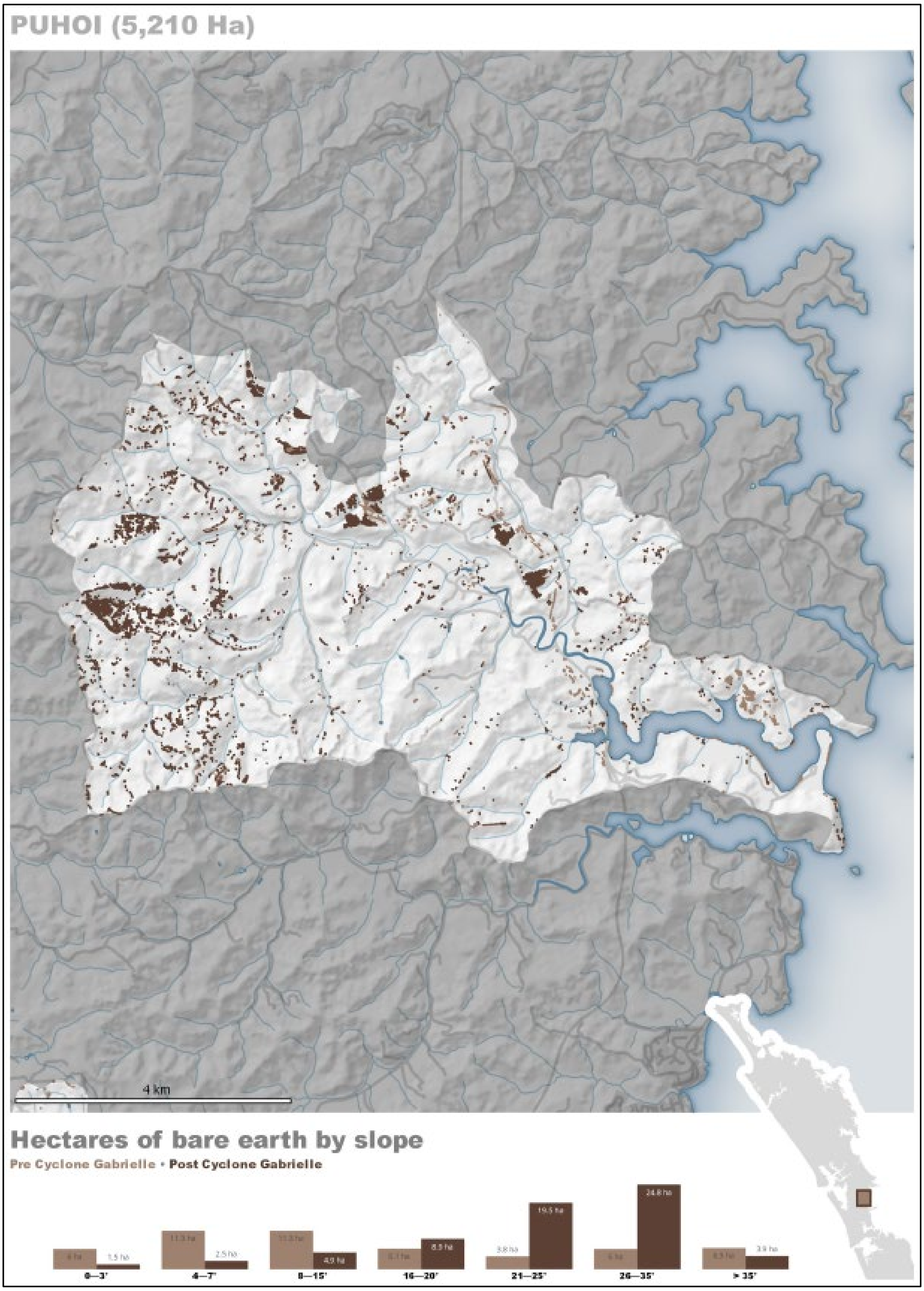

Figure 22: Pre- and post-Cyclone Gabrielle bare earth area (ha) by slope in the Puhoi catchment.

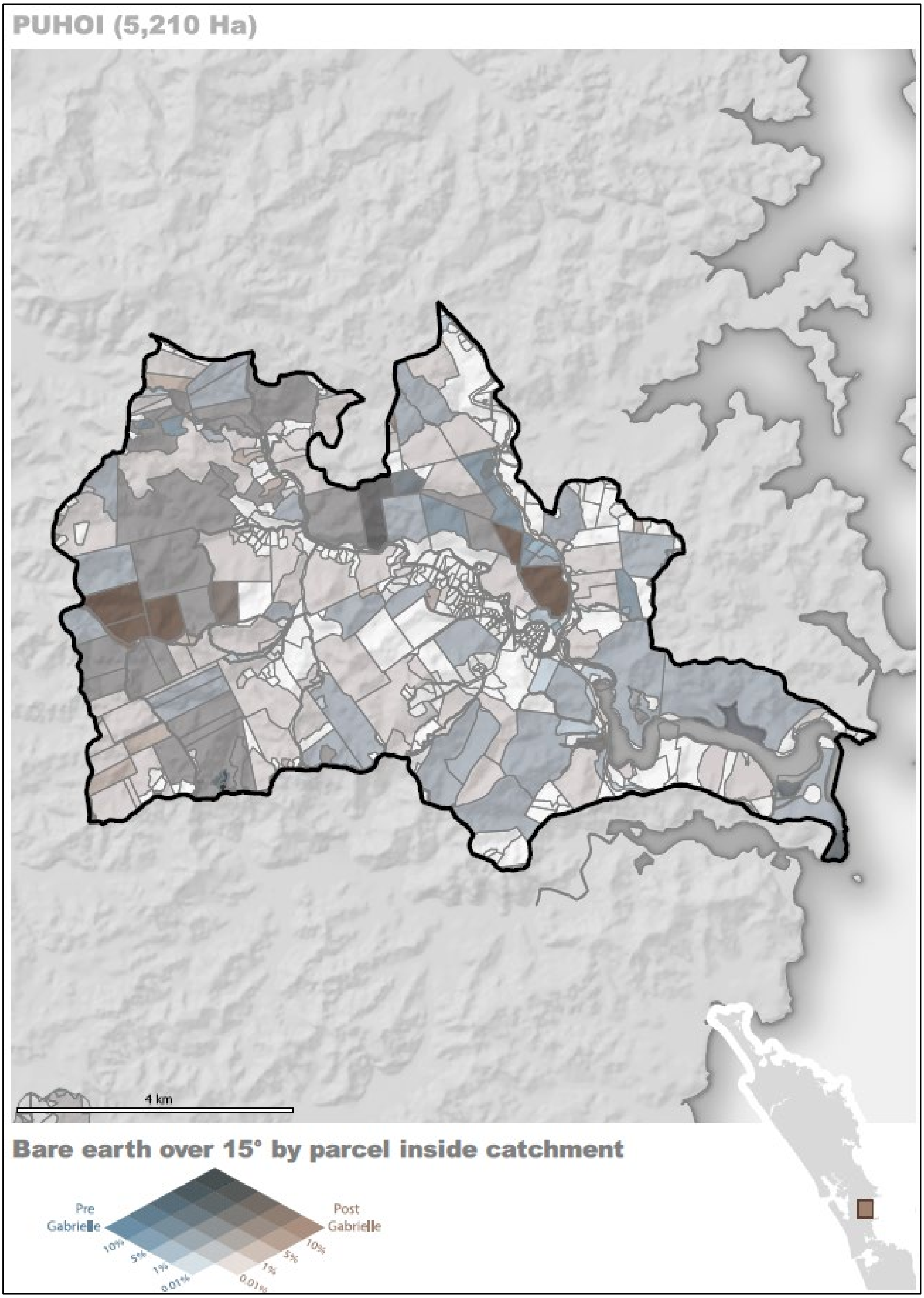

Figure 23: Parcels by percentage of pre- and post-Cyclone Gabrielle bare earth over 15° in the Puhoi catchment.

4.1.3 Kaukapakapa Catchment

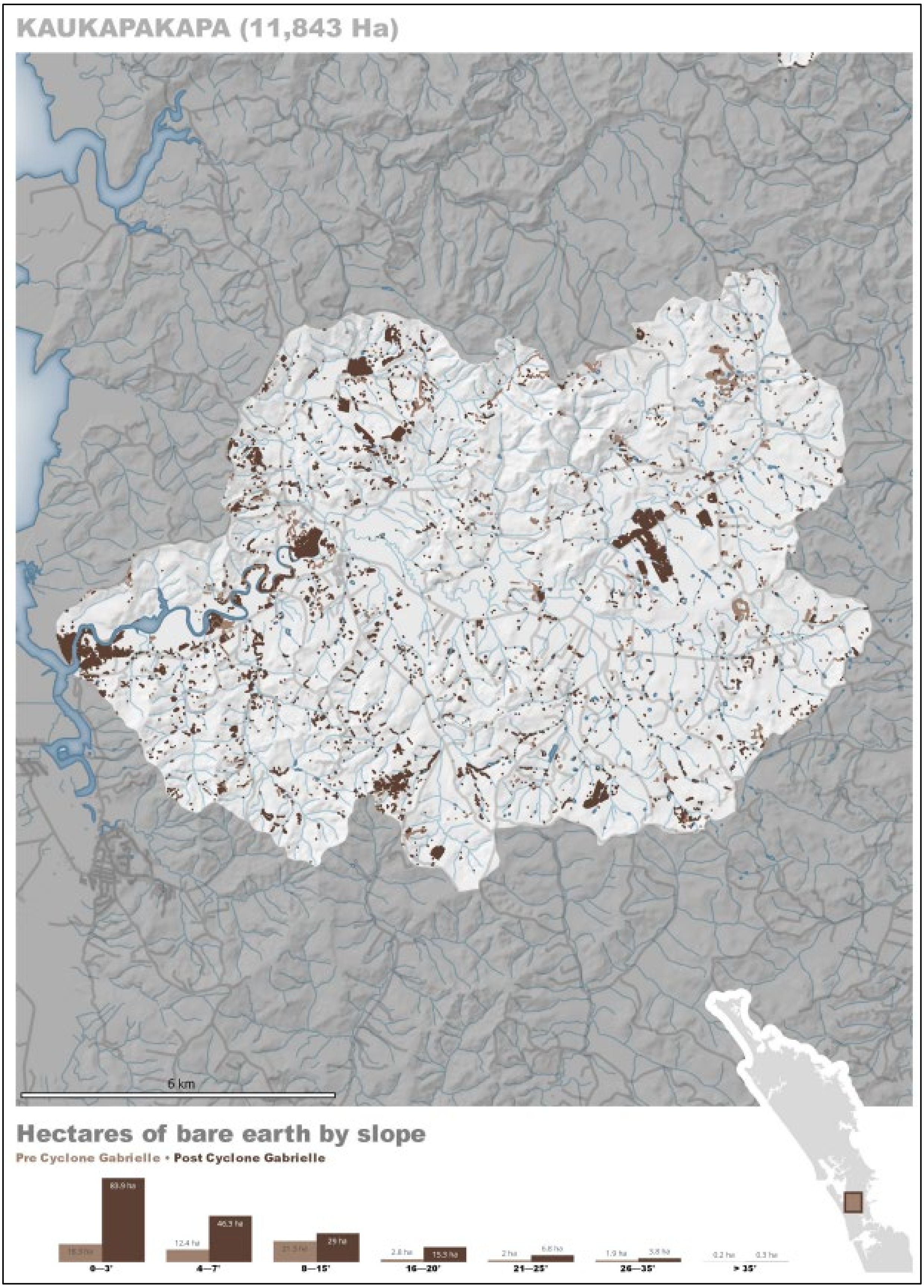

Figure 24: Pre- and post-Cyclone Gabrielle bare earth area (ha) by slope in the Kaukapakapa catchment.

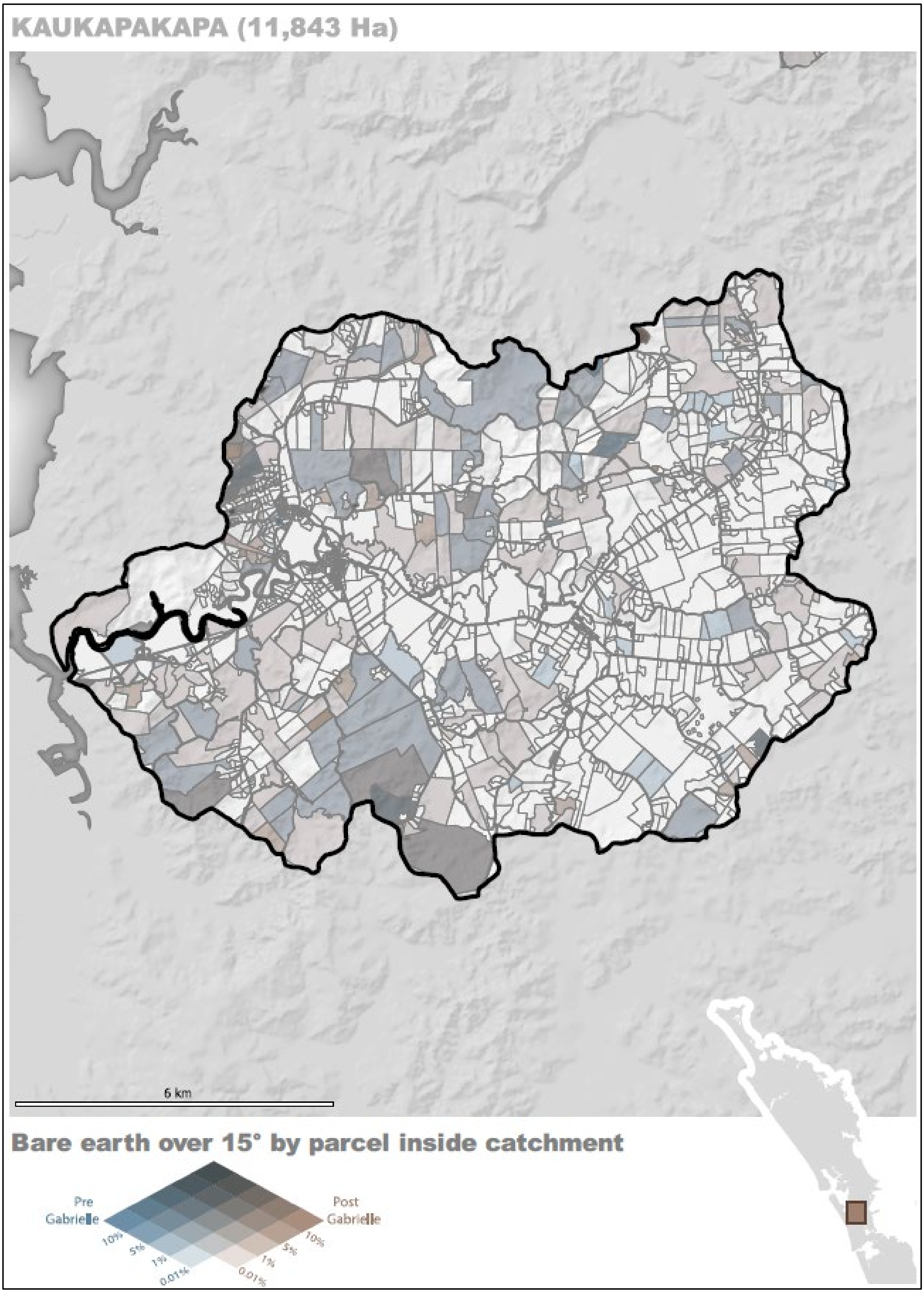

Figure 25: Parcels by percentage of pre- and post-Cyclone Gabrielle bare earth over 15° in the Kaukapakapa catchment.

4.1.4 Beachlands/Maraetai Catchment

Figure 26: Pre- and post-Cyclone Gabrielle bare earth area (ha) by slope in the Beachlands/Maraetai catchment.

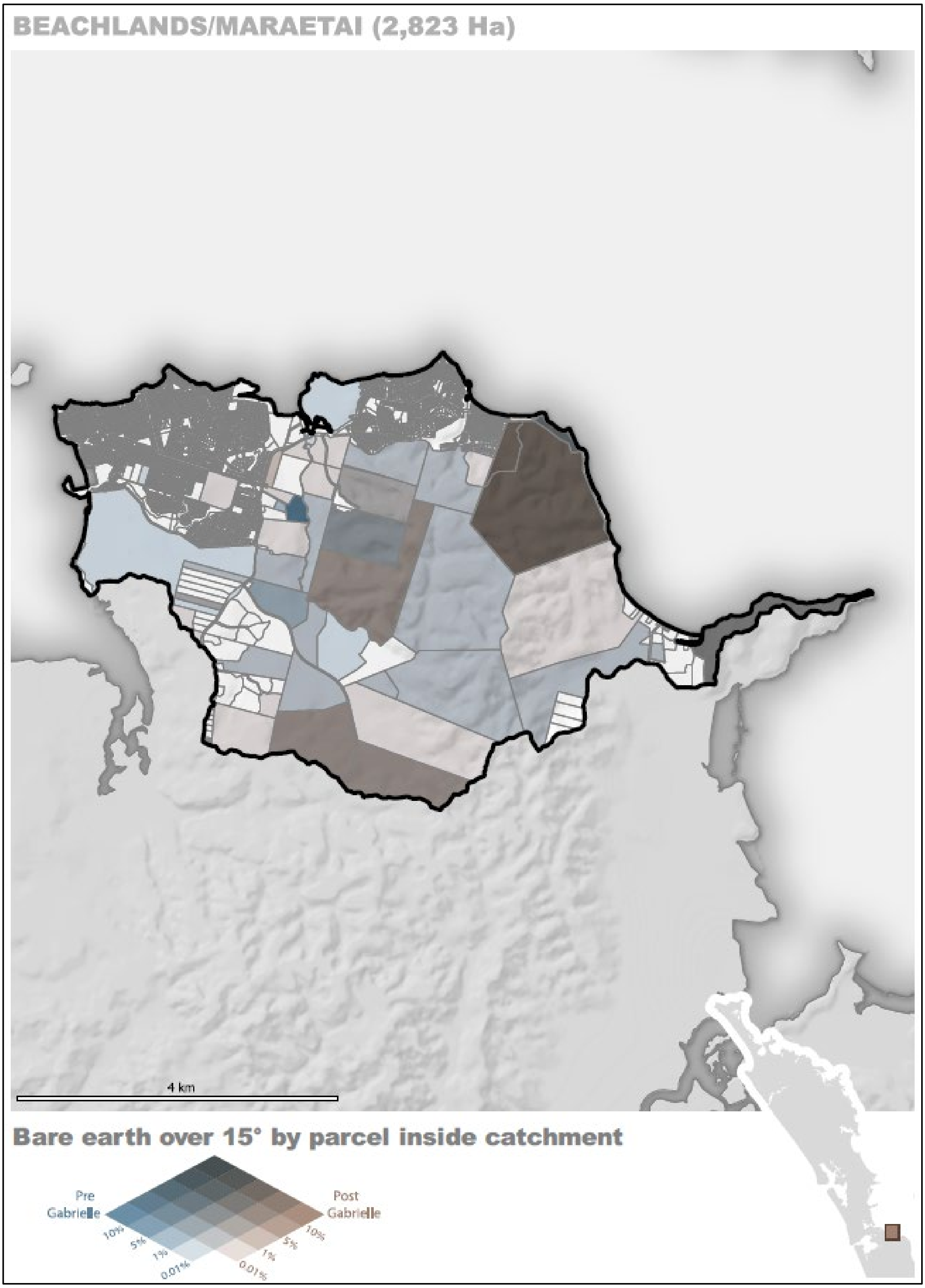

Figure 27: Parcels by percentage of pre- and post-Cyclone Gabrielle bare earth over 15° in the Beachlands/Maraetai catchment.

4.1.5 Awhitu-Manukau Harbour Catchment

Figure 28: Pre- and post-Cyclone Gabrielle bare earth area (ha) by slope in the Awhitu-Manukau Harbour catchment.

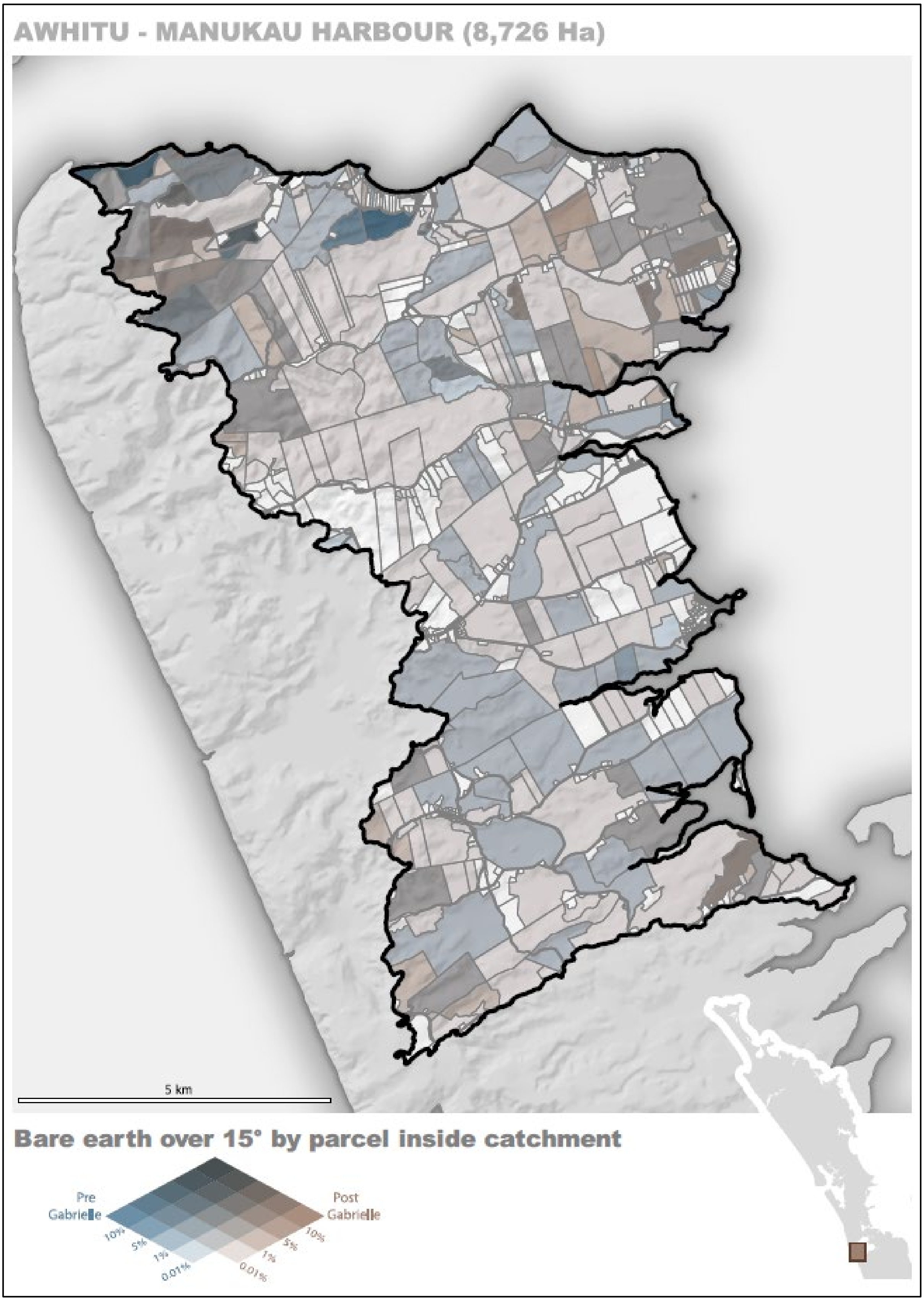

Figure 29: Parcels by percentage of pre- and post-Cyclone Gabrielle bare earth over 15° in the Awhitu-Manukau Harbour catchment.

4.1.6 Whangapouri Creek Catchment

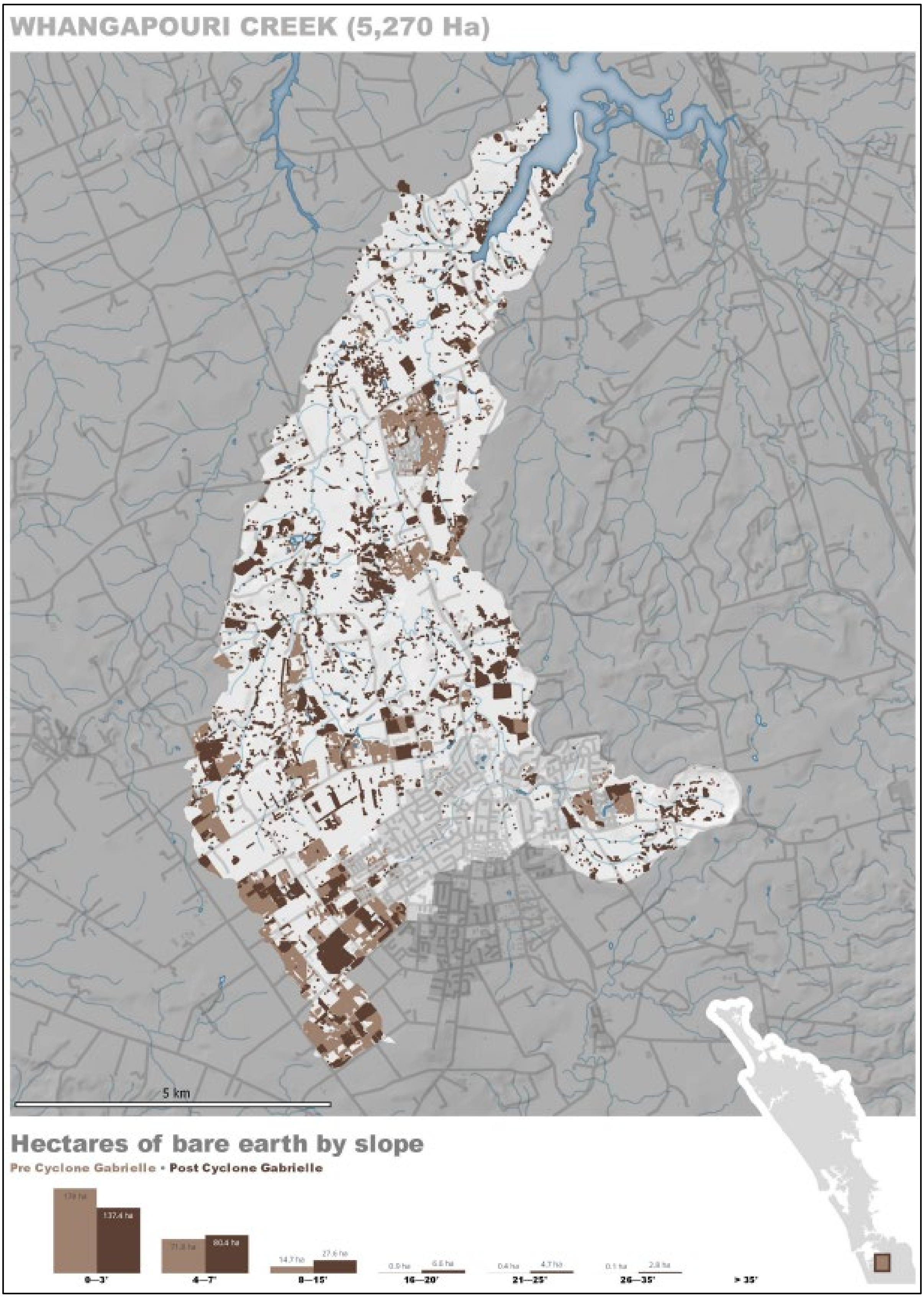

Figure 30: Pre and post Cyclone Gabrielle bare earth area (ha) by slope in the Whangapouri Creek catchment.

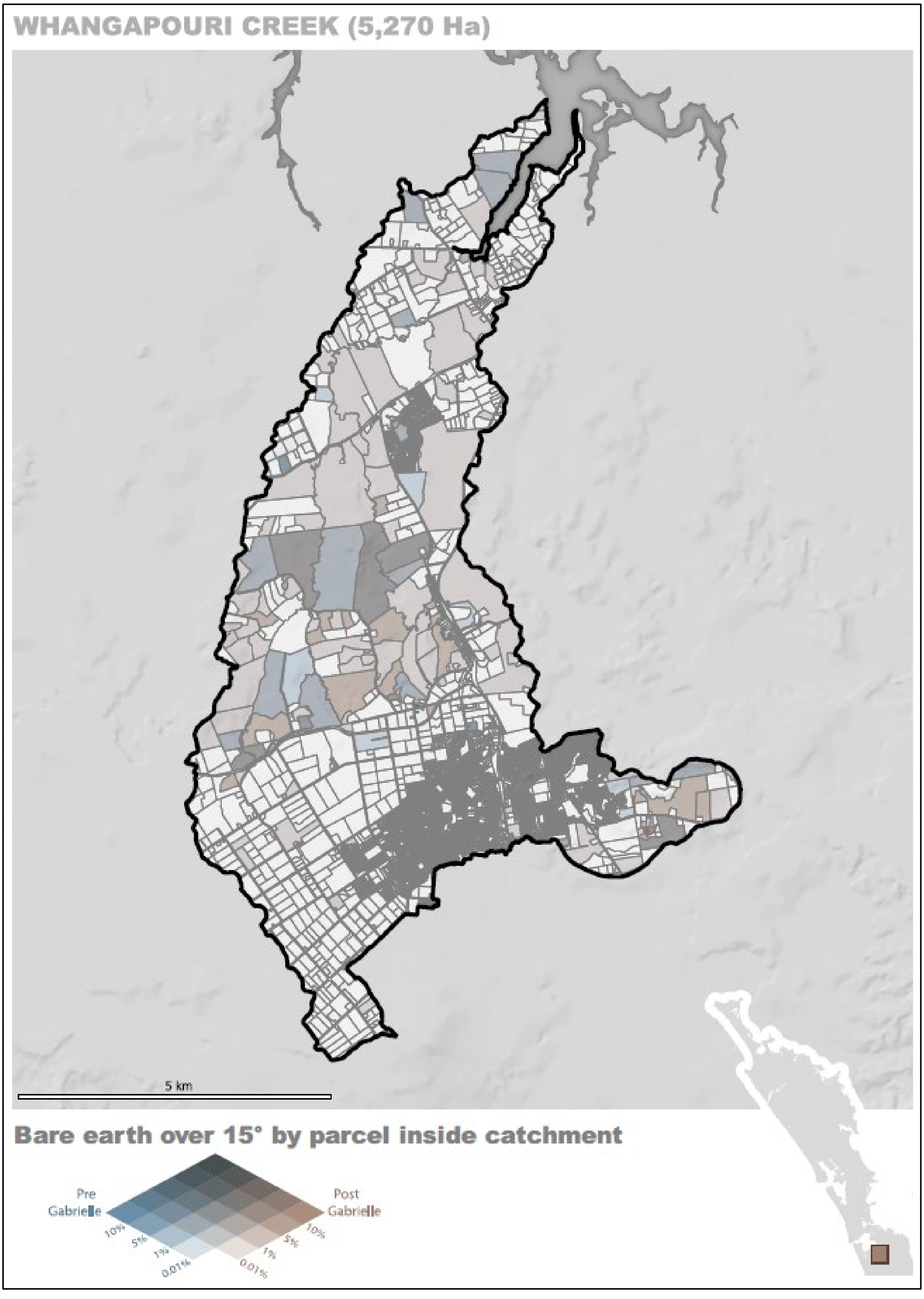

Figure 31: Parcels by percentage of pre- and post-Cyclone Gabrielle bare earth over 15° in the Whangapouri Creek catchment.

4.1.7 Auckland Sediment Sources Viewer 2024 (as part of) Post Gabrielle Sediment Study

A Web Map Viewer was created for the purposes of sharing the output data and information in spatial context. This includes bookmarks of locations within the study area that display high rates Bare Earth and other associated features interplaying such as land use cover, watercourses, and slope. The link to the viewer can be found here *[Auckland Sediment Sources Viewer 2024](#)*.

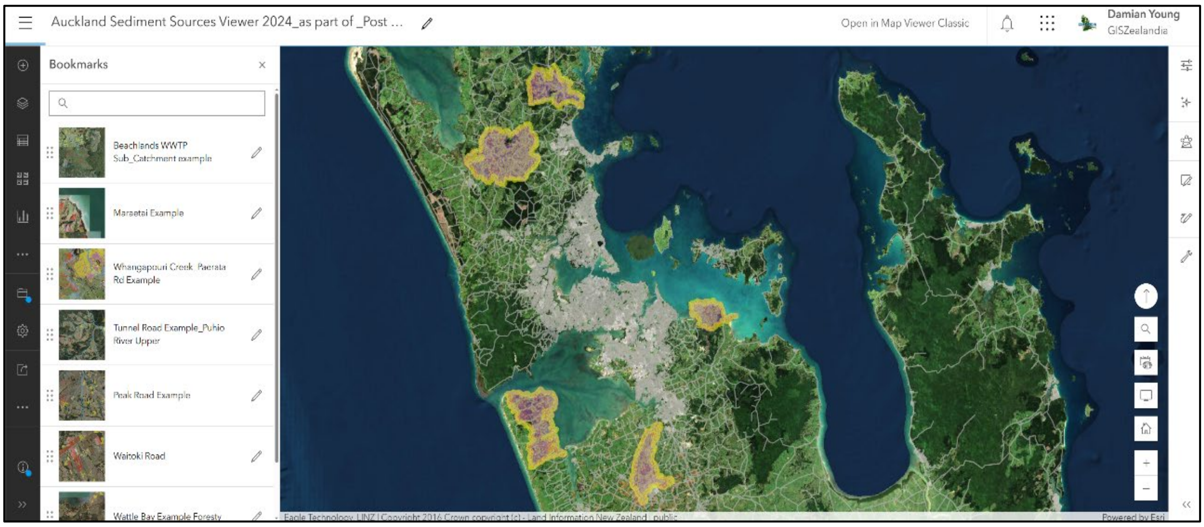

Figure 32: Screen Shot of Web Map Viewer Sediment Sources 2024.

The available data generated from the spatial analysis in this report have several applications, which are relevant to Council. Namely, data can highlight areas that were more resilient or more at risk to erosion following an adverse weather event such as Cyclone Gabrielle (e.g. Figure 33). Identified high-risk areas could then be used to better support Council to prioritise the management of these areas, including the assessment, planning, and application of solutions to increase their resilience. The Web Map Viewer is intended to provide an initial view of the potential solutions.

Figure 33: Example from Web Map Viewer along Whangapouri Creek.

4.2 OLFP Bare Earth Intersect Reporting Tool

4.2.1 Intended Purpose and Uses

The mapped Bare Earth areas were intersected with the Auckland Council Geo maps of OLFP geometry to provide an initial first cut interpretation to illustrate possible and potential sediment transport through the primary flow network (i.e. rivers and streams).

For the purposes of this exercise, no buffering was used. As a result, all the maps created and associated data are based on intersection only. This is a conservative first cut parametrisation to illustrate the potential use of the OLFP Bare Earth Intersect Reporting Tool across the region. Although this conservative approach was taken, it would be recommended to inform a wider strategic categorisation of bare earth areas for the next iterations of this pilot study by conducting:

- A 5m buffer analysis
- A 10m buffer analysis
- An intersection with mapped flood plains

The OLFP Bare Earth Intersect Reporting Tool functions to “add up” the interacted bare earth areas to provide a high level spatial intersect tool to better inform prioritisation and categorisation of bare earth areas. It is recommended, therefore, that the following should be undertaken in addition to the buffering outlined above:

- Type 1 bare earth (not in flood plains and/or intersection a 10m buffered OLFP)
- Type 2 bare earth (being in a flood plain and intersecting with 10m buffered OLFP)

4.2.2 Examples of Tool Application

The following figures (34-38) are intended to illustrate the intersection of bare earth and OLFP and the distribution of bare earth throughout the catchment. The accumulation of the intersected bare earth areas was calculated to demonstrate the total areas potentially discharging to the coastal marine environment as indicated by red circles.

Puhoi Catchment

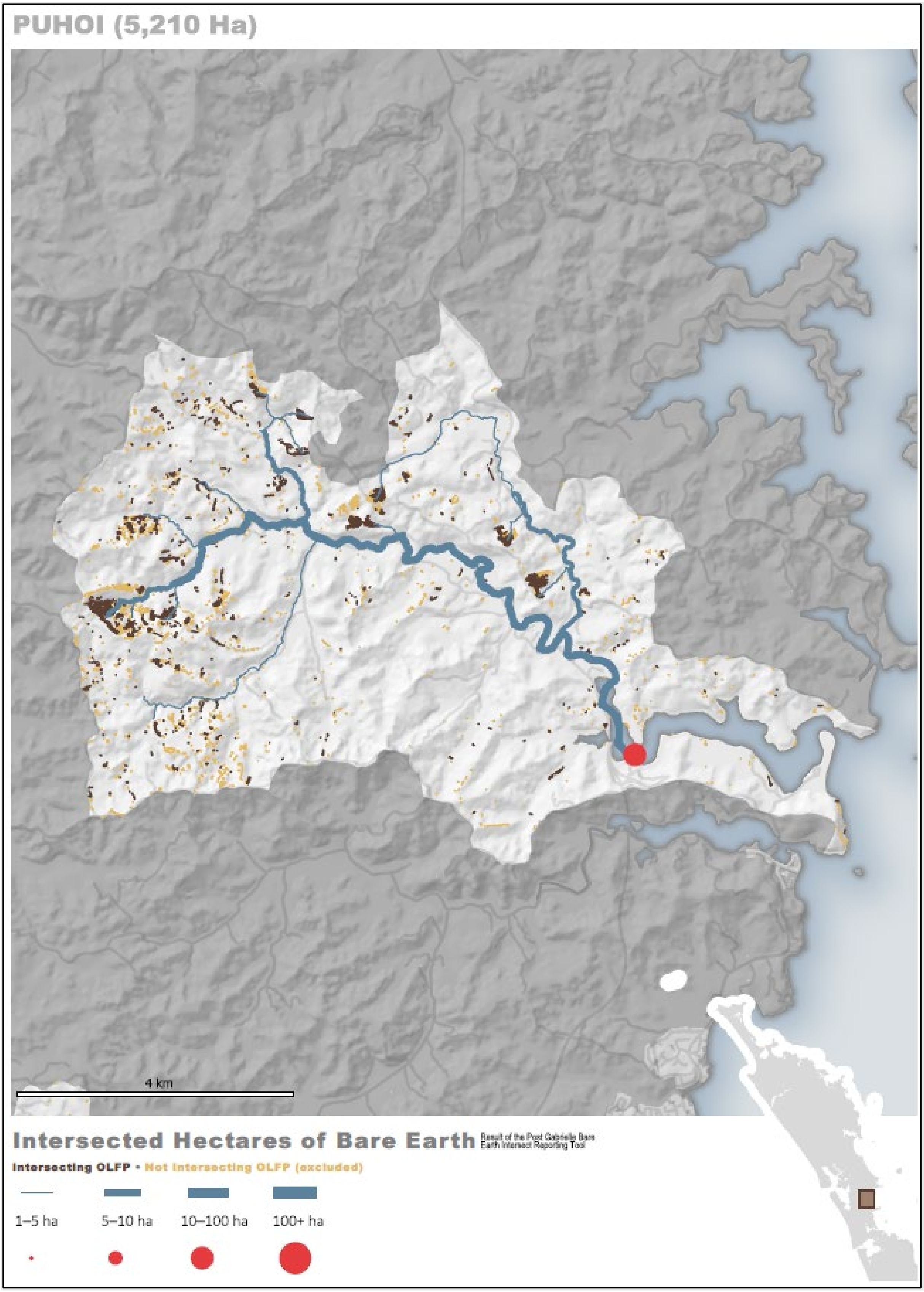

Figure 34: Intersected bare earth areas (ha) with overland flow paths in the Puhoi catchment.

Kaukapakapa Catchment

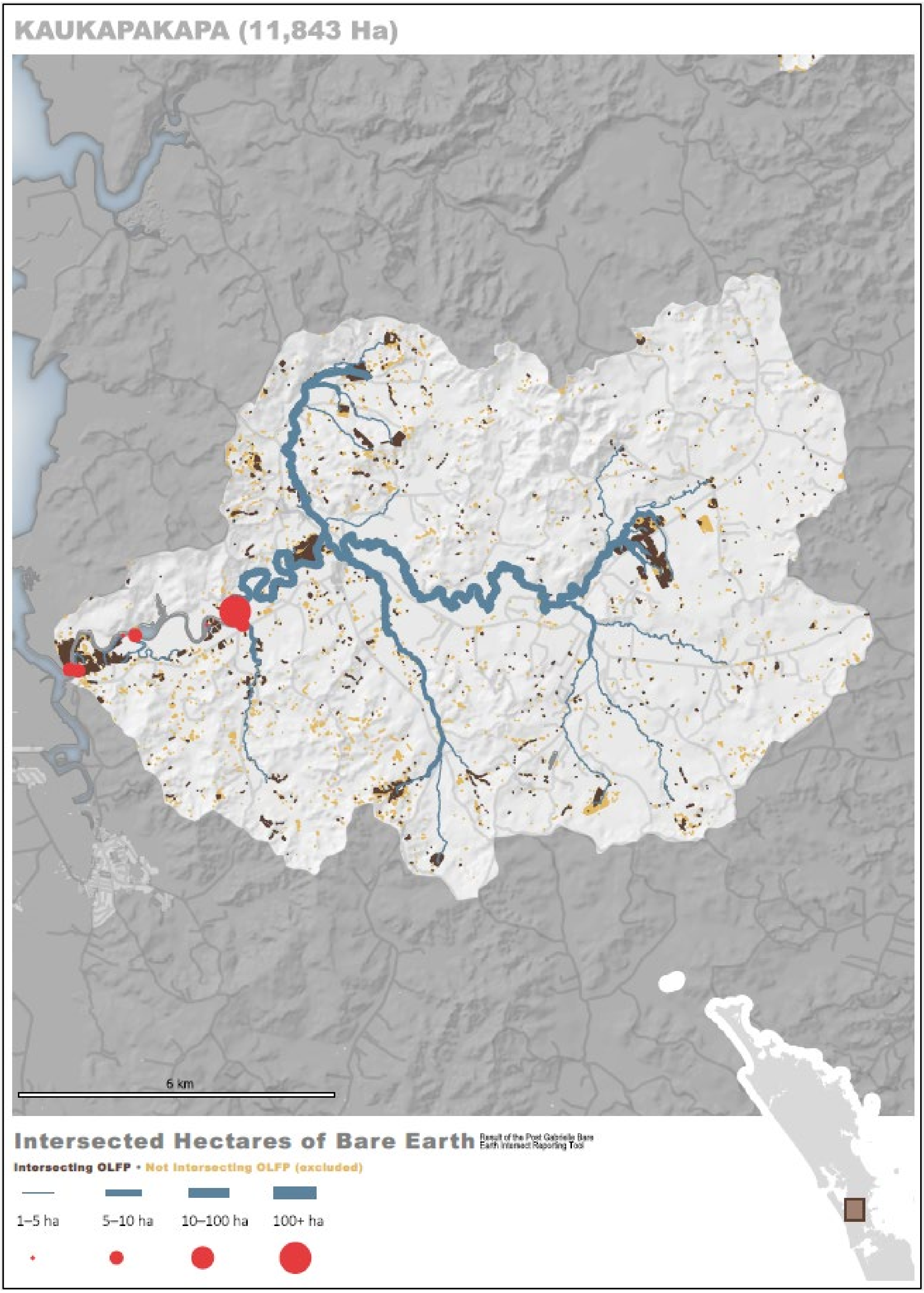

Figure 35: Intersected bare earth areas (ha) with overland flow paths in the Kaukapakapa catchment.

Beachlands/Maraetai Catchment

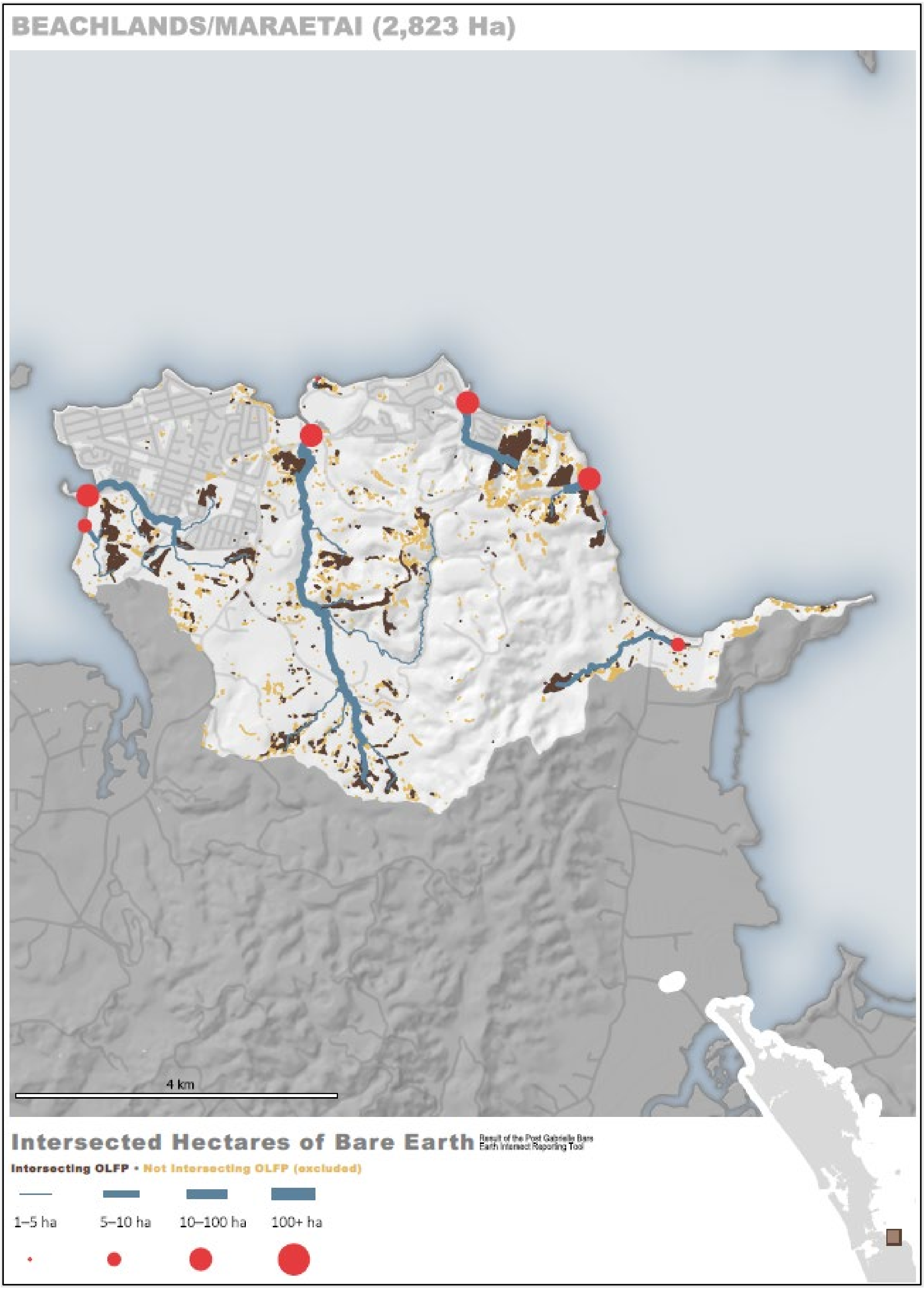

Figure 36: Intersected bare earth areas (ha) with overland flow paths in the Beachlands/Maraetai catchment.

Awhitu-Manukau Harbour Catchment

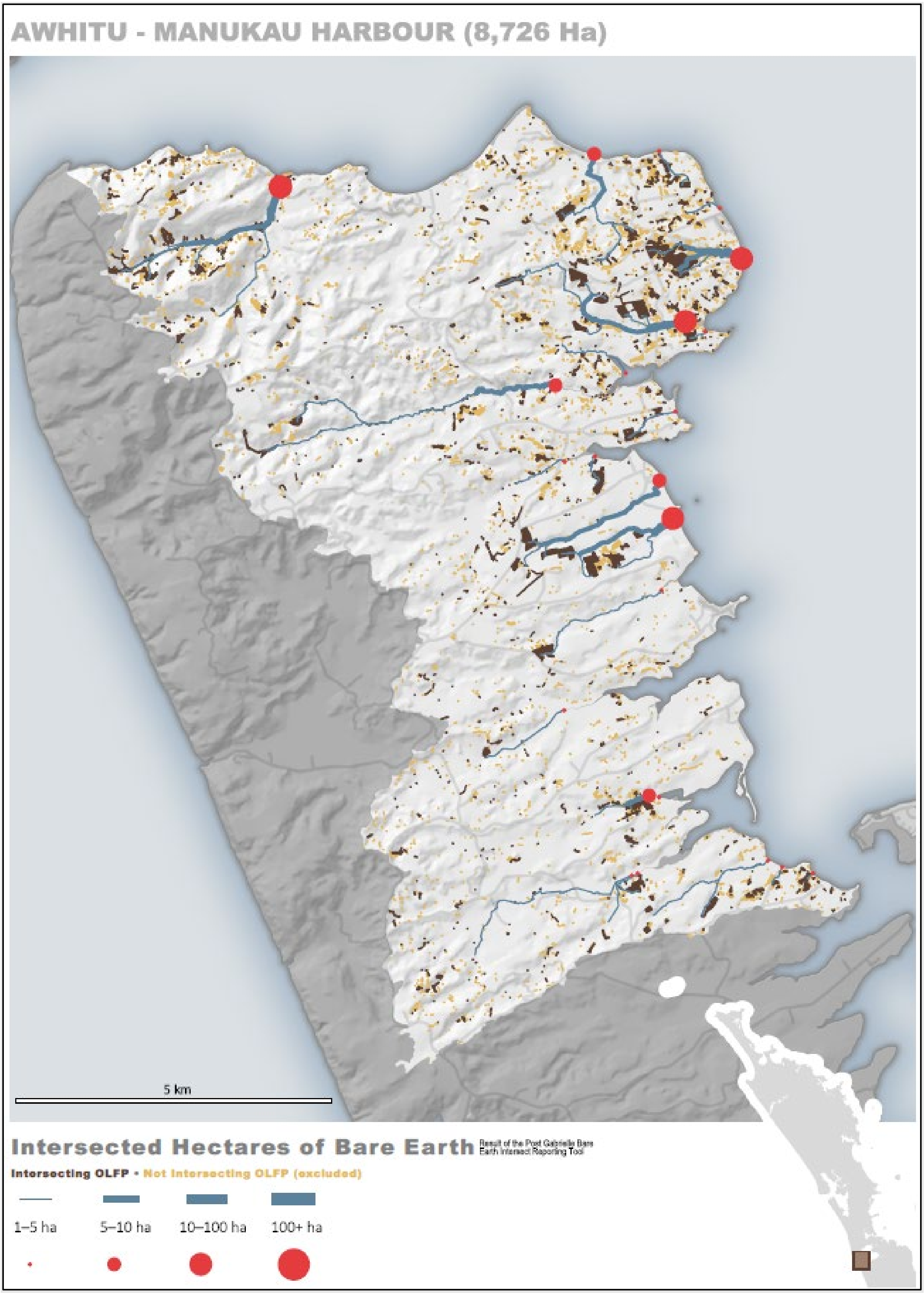

Figure 37: Intersected bare earth areas (ha) with overland flow paths in the Awhitu-Manukau catchment.

Whangapouri Creek Catchment

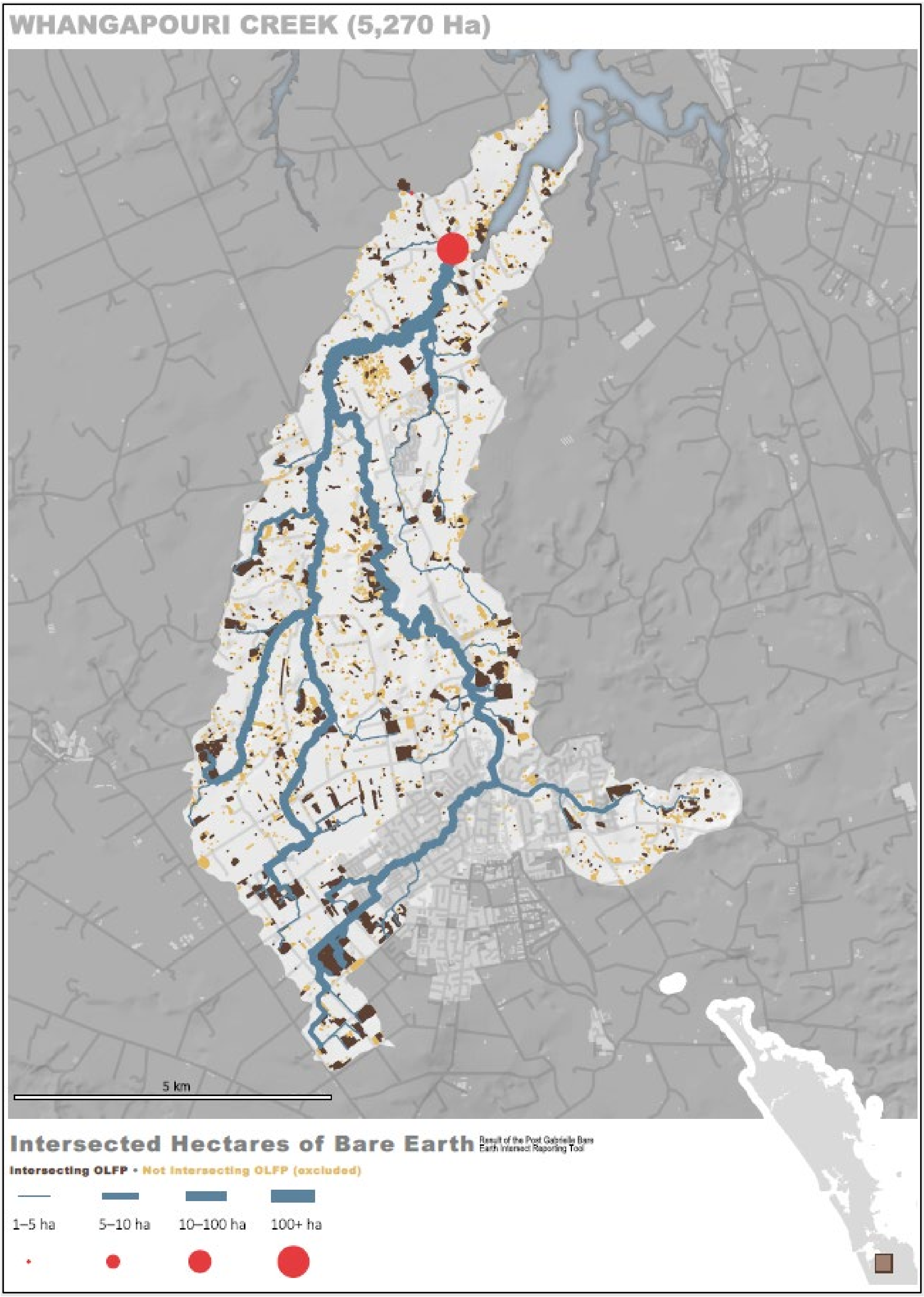

Figure 38: Intersected bare earth areas (ha) with overland flow paths in the Whangapouri Creek catchment.

5 Final Data Deliverables

The list of contracted data and report deliverables is as follows:

- Technical Development Report
- Bare Earth Coverage Layer
- A Map Viewer in ArcGIS (@ ESRI), entitled "*Auckland Sediment Sources Viewer 2024*"

6 Summary and Key Benefits

The Pre- and Post-Gabrielle Bare Earth Coverage (Lynker, 2024) is the key deliverable of this project. The associated five pilot catchments were selected based on the reported and observed damage and impact observed by Council and because they provide a range of catchment types to test the GIS analysis methods. The modelling outputs highlighted the following:

- A high-quality bare earth geometry can be developed cost effectively with multiple applications.
- Land Title Coverage can be used as a core reporting unit.
- Changes in bare earth can be observed in near real-time or within a short-time frame.
- A good indicator on the usefulness of the various types of satellite imagery available can be very useful. The adequate satellite imagery is dependent on the resolution of that imagery and specific project requirements (e.g. 3m vs 0.3m resolution). For example, free or lower resolution imagery could be used to identify areas of interest. High-resolution imagery could then be accessed to provide a higher certainty for these areas of focus.
- A Map Viewer can be created to access the available data at property scale as well as other relevant layers.
- The simple geospatial modelling and tools can be repeated and adapted to specific project requirements. For example, bare earth distribution conducted in conjunction with a buffer analysis (e.g. 5m and 10m buffer) and an intersection with mapped flood plains could help develop sedimentation trapping strategies.

Key strategic benefits from this pilot work include the following:

- Highlighting the need to undertake analysis at a catchment level/unit, when applicable, due to the uniqueness of these catchments even at a regional level due to differences in geology, topography, land use, land cover, etc. Caution should, therefore, be applied when attempting to apply regional- and national-based policies as these might not be relevant or adequate for a given area of interest.
- Providing the geospatial stepping stones through high resolution regional aerial imagery analysis to classify areas that might be bare earth as well as those areas more prone to erosion and runoff following adverse weather events. The classification of these areas can then help support and implement a more cohesive, cost effective, and performance driven response to Regional Sediment Management by prioritising high-risk areas. For example, very steep pastural land areas, including gullies, could be retired and afforested to reduce the likelihood of erosion in the future (Zuazo & Pleguezuelo, 2009; Basher, 2013). Infrastructures at risk or playing a role in localised erosion (Cerdà, 2007; Schlögl & Matulla, 2018; Young et al., 2024)

could also be managed as a priority to make them more resilient as part of a critical assessment.

- Generating the Pre- and Post-Gabrielle Bare Earth Coverage to inform the development of planning, policy, and environmental initiatives, focused on sediment source and effects.
- Providing a “first cut” spatial plan, for engagement with landowners, Tangata Whenua, and communities, which can serve to prioritise areas to improve the overall condition and quality of receiving environments by managing potential sediment runoff, erosion/slips, and transport.
- Providing a Regional Coverage and a set of customisable GIS Tools to meet requirements/drivers set out in the National Policy Statement for Freshwater Management (NPS-FM), Freshwater Farm Plans (FWFPs), and/or consent/permit processes.

Further applications from this pilot work include the following:

- Development of a Sediment Sources Rapid Identification and Management System and Viewing portal to provide Council Officers with more transparency and access to the data, which has been developed as part of this study.
- Application of buffering of the OLFP geometry to establish a green-finger/sediment management coverage. This could be included to support Council when it considering options and local project drivers for the “Making Space for Water Programme” and other integrated planning initiatives such as the Freshwater Management Tool.
- Application of the model and tools as a monitoring tool. For example, it could be applied post implementation of management strategies to assess how effective these measures were at, for example, increasing resilience to flooding and at preventing and/or reducing erosion following significant weather events (e.g. retiring and afforesting high risk areas).
- Implementation of a sequence of tools to provide a real-time monitoring of high-risk areas prone to erosion for Council Management Team.
- Creation of a Cosmopolitan Tool Suite integrating all relevant tools (e.g. The Coastal Receiving Environment Scenario Tool or CREST by DHI Water & Environment Ltd)and layers (e.g. hazard maps; Council assets) to better support Council to prioritise the management of areas of high risks, as well as to better assess, plan, and apply strategies/solutions the regional landscape, environment, and assets (e.g. Blue/Green Network; Healthy Waters). This Cosmopolitan Tool Suite could also form a strong base for future Council Action Plans and test their fitness for purpose as well as provide evidence required to support changes in policies.

7 Data Issues and Limitations

7.1 Data Issues

7.1.1 Weather conditions

Parts of the Auckland area from the pre- (© Planet Labs PBC) and post-Cyclone Gabrielle (© Maxar Technologies) satellite imagery were cloudy (Figure 39). This affected the bare earth inference, as both cloud and cloud shadow mean the model cannot predict reliably. These areas which were small in terms of total land area were excluded from the analysis i.e. not predicted to contain bare earth.

Figure 39: Example of Maxar satellite imagery showing clouded areas (grey), which affected the estimation of bare earth areas.

7.2 Data Limitations

In this pilot study, the following limitations were identified:

- Model uncertainty in heavily shadowed areas - steep slopes, tall trees imaged with a low sun angle may cause extensive shadows. We have used image correction to minimise such impacts but occasionally shadows will result in misclassifications.
- Dry pasture with minimal dry matter along with recent mowing/hay baling may present as bare earth. However, these areas do not generally originate sediment.
- Small areas of cloud exist in some of the satellite images. The model does not predict in these areas.
- Soil from a land slip will tend to displace down slope and cover vegetated areas, meaning bare earth is then shown both on the slipped face, as well as over the slip distribution areas.

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9 Appendices

9.1 Tools Used

9.1.1 Machine Learning

Creation of the *bare earth model* and *sediment scenario analysis* used the following Python libraries:

- Python 3.9
  - scikit-learn
  - rasterio
  - InterpretML
  - Tensorflow

9.1.2 Geospatial processing

Including the *bare earth resulting from Cyclone Gabrielle analysis* and the *OLFP Bare Earth Intersect Reporting Tool* used the following tools:

- ArcGIS Pro (v3.2)
- ArcPy (arcgis-pro-py3)
- QGIS
  - 3.36.0 on Windows
  - 3.36.2 on Windows
- GDAL
  - v3.8.4 via Windows command line
  - v3.4.3 via Linux command line
- PostgreSQL
  - on AWS RDS
    - PGSQL=15.50
    - POSTGIS=3.4.0
    - GEOS=3.11.2-CAPI-1.17.2
    - PROJ=8.0.1
  - on Windows
    - PGSQL=160
    - POSTGIS=3.4.0 3.4.0
    - GEOS=3.12.0-CAPI-1.18.0
    - PROJ=8.2.1

9.2 Comparison of Bare Earth Areas (ha) Pre- and Post-Cyclone Gabrielle by Catchment and Slope Class for this Pilot Study

Table 5: Comparison of bare earth areas (ha) pre- and post-Cyclone Gabrielle by catchment and for all slope classes.

Catchment area	Slope class	Total bare earth (ha)	bare earth (ha) pre-cyclone	Percentage of total bare earth area pre-cyclone	bare earth (ha) post-cyclone	Percentage of total bare earth area post-cyclone	Percentage	Change
AWHITU - MANUKAU HARBOUR (8,726 Ha)	0—3°	46	1.3	2.9	44.7	97.10	3,295	increase
	4—7°	36.7	1.8	4.9	34.9	95.10	1,859	increase
	8—15°	54.6	3.2	5.8	51.4	94.20	1,510	increase
	16—20°	20.3	0.7	3.3	19.7	96.70	2,819	increase
	21—25°	17.5	2.7	15.5	14.8	84.50	445	increase
	26—35°	31.3	7.1	22.5	24.3	77.50	244	increase
	> 35°	11.7	2.4	20.6	9.3	79.40	285	increase
	Total	**218.2**	**19.2**	**8.8**	**199.1**	**91.20**	**939**	**increase**
BEACHLANDS/MARAETAI (2,823 Ha)	0—3°	17.8	3	16.8	14.8	83.20	395	increase
	4—7°	39.2	14.1	35.9	25.1	64.10	79	increase
	8—15°	14.1	5.1	36.1	9	63.90	77	increase
	16—20°	28.4	2.6	9.3	25.7	90.70	876	increase
	21—25°	27.2	2.4	8.9	24.7	91.10	918	increase
	26—35°	15.2	7.9	52.2	7.3	47.80	9	decrease
	> 35°	1.4	0.7	48.6	0.7	51.40	6	increase
	Total	**143.1**	**35.8**	**25**	**107.3**	**75.00**	**200**	**increase**
KAUKAPAKAPA (11,843 Ha)	0—3°	102.1	18.3	17.9	83.9	82.10	359	increase
	4—7°	58.7	12.4	21.1	46.3	78.90	275	increase
	8—15°	50.3	21.3	42.3	29	57.70	36	increase
	16—20°	18.2	2.8	15.7	15.3	84.30	439	increase
	21—25°	8.8	2	22.4	6.8	77.60	246	increase
	26—35°	5.7	1.9	32.9	3.8	67.10	104	increase
	> 35°	0.5	0.2	41.3	0.3	58.70	42	increase
	Total	**244.3**	**58.8**	**24.1**	**185.5**	**75.90**	**215**	**increase**

Catchment area	Slope class	Total bare earth (ha)	bare earth (ha) pre-cyclone	Percentage of total bare earth area pre-cyclone	bare earth (ha) post-cyclone	Percentage of total bare earth area post-cyclone	Percentage	Change
PUHOI (5,210 Ha)	0—3°	7.5	6	79.6	1.5	20.40	74	decrease
	4—7°	13.8	11.3	81.6	2.5	18.40	78	decrease
	8—15°	16.3	11.3	69.7	4.9	30.30	57	decrease
	16—20°	15	6.1	40.5	8.9	59.50	47	increase
	21—25°	23.3	3.8	16.5	19.5	83.50	408	increase
	26—35°	30.9	6	19.6	24.8	80.40	311	increase
	> 35°	10.3	6.3	61.6	3.9	38.40	38	decrease
	Total	**117.1**	**50.9**	**43.5**	**66.2**	**56.50**	**30**	**increase**
WHANGAPOURI CREEK (5,270 Ha)	0—3°	315.4	178	56.4	137.4	43.60	23	decrease
	4—7°	152.1	71.8	47.2	80.4	52.80	12	increase
	8—15°	42.3	14.7	34.8	27.6	65.20	87	increase
	16—20°	7.4	0.9	11.7	6.6	88.30	654	increase
	21—25°	5.2	0.4	7.9	4.7	92.10	1,061	increase
	26—35°	2.9	0.1	2.3	2.8	97.70	4,107	increase
	> 35°	0	0	0	0	0.00	-	No Change
	Total	**525.3**	**265.8**	**50.6**	**259.5**	**49.40**	**2**	**decrease**

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