REPORT

Tonkin+Taylor

Waimatā Nature Based Solutions Toolbox Summary Report

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Executive summary

Gisborne District Council (GDC) has engaged Tonkin & Taylor Ltd (T+T) to develop a bespoke modelling toolbox to help appraise the potential effectiveness of Nature Based Solutions (NBS) in the Waimatā catchment. This work was prompted by the impacts of a succession of storms in the catchment, culminating in Cyclone Gabrielle in February 2023. The aim was to assess a range of possible NBS to mitigate the impacts of large storms and their associated flood impacts in the Waimatā catchment, in particular to tackle problems associated with erosion, sedimentation and woody debris, which were prevalent in Cyclone Gabrielle. The Toolbox uses predictive models to help identify the most vulnerable areas exposed to erosion, sedimentation and woody debris generation the effectiveness of various NBS options, both at the subcatchment level, as well as at the level of the entire catchment system to prioritise areas for land use change to mitigate the effects of storms in the catchment. To explore the feasibility of NBS options in the Waimatā catchment GDC has received funding from the Ministry for the Environment (MfE).

The intention of the Toolbox is to support GDC and its stakeholders in potential land use change decisions in the Waimatā catchment, with the aim of reducing:

- Erosion/sediment generation.
- Woody debris generation and transportation.

The Toolbox should only be used as a high-level feasibility assessment tool by GDC staff, enabling them to assess the potential efficacy and impact of various NBS options to reduce sediment and woody debris loads in various subcatchments within the Waimatā River system.

The Waimatā River comprises steeply dissected valleys and terrace constrained floodplains, which essentially act as a flume, flushing flows, debris, and sediment through the system. During large storms, these factors contribute to ongoing woody debris, sediment and flooding issues throughout the catchment, affecting environmental, cultural, and recreational values and posing threats to property and infrastructure. Due to the unique nature of this catchment, there are a limited range of NBS options that can be applied effectively. Sensitivity testing of the Toolbox, alongside local knowledge, has indicated that once sediment has entered the main stem of the river, there is a limited level of improvement that NBS tools can affect, in terms of their ability to reduce sediment/debris transport and alleviate flooding downstream. Therefore, the main areas of focus for NBS in this catchment should be in tributary subcatchments, particularly in the mid to upper catchment.

Afforestation and riparian plantings are the most effective NBS within this catchment, underpinning long-term landscape-scale benefits. Small scale retention/detention and vegetative debris buffers provide localised improvements but are expected to be most effective in small events and much less effective in extreme events such as Cyclone Gabrielle.

Recommended Toolbox Use

The outputs from the Toolbox should be used as an initial guide to inform users of the potential effects of different NBS options within the Waimatā Catchment. These outputs should not be treated as wholly comprehensive or definitive. It is the user’s responsibility to interpret these outputs holistically, informed by broader social, economic, and cultural considerations. For more precise and definitive information, users should combine this Toolbox's findings with additional detailed analysis at site scale. This could include flood modelling, geomorphic assessments, as well as social, cultural and cost feasibility analysis.

In short, while this model can provide insights on effective NBS options, more detailed exploration and design work will be needed before implementation of NBS strategies can proceed.

Uses, constraints and limitations

With any tool, it is crucial to understand and acknowledge the intended uses, constraints and limitations:

- The Toolbox should be used as an initial guide to inform potential NBS options for GDC to investigate within the Waimatā Catchment. The Toolbox will provide the user with high level NBS options in locations around the catchment and will output relative effectiveness of those NBS options in relation to mitigating sedimentation, erosion, and woody debris effects.
- NBS options tend to be more effective during smaller magnitude (more frequent) storm events, and within a localised area. It should be noted that the models utilised in this Toolbox are trained using the high magnitude, low frequency Cyclone Gabrielle event. Therefore, the relative effect of a discrete NBS option may appear less significant in the model when compared with its potential effect in an event smaller than Cyclone Gabrielle, and in a localised downstream area.
- The models included in the Toolbox have been specifically trained on the Waimatā Catchment. Additional model training and calibration tool approaches are provided in the Toolbox User Guide Manual, together with the Toolbox, to assist GDC with implementation in other catchments. It must be acknowledged however, that this aspect is not included in the Toolbox itself, so re-application to a different catchment will require knowledge of the Python programming language and Data Science and GIS expertise. In addition, appropriate data inputs need to be established for new catchments such as Geomorphic Change Detection (GCD) analysis, and tolerance mapping.
- The Toolbox is data-driven; therefore, the output quality is dependent on the input quality. The Toolbox uses the data and information available at the time the project was undertaken, however there are likely to be opportunities to re-train and re-calibrate the model using higher quality and/or more up-to-date data in the future.
- The Toolbox has been developed using a semi-quantitative approach and considers the effect of NBS in comparison to a Cyclone Gabrielle sized event. The Toolbox models involve quantitative estimates for event impact and qualitative estimates for tolerance which are combined using a qualitative scoring framework to give NBS scores that can be used for prioritisation. Other detailed information regarding economic, social and cultural considerations should be used in conjunction with the outputs of the NBS Toolbox.
- A hydrological model was not incorporated within the spatial tool given the associated uncertainty with a simplistic runoff estimation approach and to avoid inconsistency with other more detailed hydraulic modelling efforts in progress across Tairawhiti and in this specific catchment. This should not be taken to imply that flooding is not an important consideration and detailed hydraulic modelling data could be included in future updates.
- The Toolbox can be used to predict the NBS options most suitable for a given subcatchment to reduce erosion, sedimentation, and woody debris. High-level sizing options for some NBS have been provided in the Toolbox (e.g., planting and debris traps) and the relative effectiveness given that size. However, the Toolbox should not be used to precisely locate, size or design NBS options within the catchment.

Exclusions

- Hydrological model and surface runoff: It should be noted that due to hydrological modelling work already underway in Tairawhiti, it was agreed not to progress modelling of surface runoff at this stage to avoid duplication of effort and potential inconsistencies between approaches (see limitations below). Nevertheless, opportunities for flow and sediment dispersal in conjunction with sediment retention within low-risk areas of the network have been considered. It should also be noted that NBS options targeting reduction in sediment erosion will have an impact on surface runoff, but the extent and specifics of this should be considered in more detail once hydrological modelling in the region has been completed and can be applied alongside the tool presented here.

- Culvert daylighting: It has been discussed and agreed with GDC that the culvert daylighting be excluded from this scope of works due to the limited data available. The analysis of the data provided indicated gaps in the base data, which caused errors in the models skewing results and resulting poor predictions. The culvert daylighting can be incorporated into the future works given more reliable data is available.
- Two stage channels: Two staged channels were excluded from the analysis due to the space restrictions.

1 Introduction

Tonkin & Taylor Ltd (T+T) has been engaged by Gisborne District Council (GDC) to develop a spatial toolbox that will identify areas within the landscape where Nature Based Solutions would provide resilience to sediment, flow and woody debris migration into the river system.

This work has been undertaken in accordance with our Offer of Service dated 19 September 2024. The service has been conducted in accordance with the terms and conditions set out in Contract for Services 24-104 Nature-based Solutions - Waimatā (dated 31/10/2024).

2 Purpose and objectives

The purpose of this project is to develop and deliver a Geographic Information System (GIS) based toolbox, designed to identify potential locations for the effective implementation of Nature Based Solutions (NBS) to mitigate erosion, sedimentation, and woody debris issues within the landscape. The Toolbox aims to assist GDC by supporting land use decision-making processes.

The Toolbox can assist in the decision-making process, by providing a 'first step' of what and where to implement NBS, serving to guide the user in their judgment rather than providing a definitive directive of 'do this here'. It is important that the user evaluates all inputs and scenarios generated by the Toolbox and makes informed decisions about the optimal course of action.

Our objectives align with the description of services and stipulated requirements outlined in the contract (24-104 Nature Based Solutions – Waimatā, dated 31 October 2024). More specifically, the objectives include:

1. Developing a Toolbox that integrates existing datasets and enables the testing of a variety of NBS to support decisions relating to land stabilisation (erosion) and reduction of sediment, woody debris generation and transportation (excluding river discharge estimation).
2. Delivering a Toolbox that can help identify intervention locations, determine the most effective type of NBS for those locations, and assessing the feasibility of implementing these interventions. Feasibility, as defined for the purpose of this project, is the physical efficacy of an NBS option.

Further objectives were established and confirmed by the Project's Governance Group during the first workshop (refer to Table 2.1). Note that the 'Possible Phase 2 Objectives' sit outside of the scope of this current project and can be incorporated in the potential future Phase 2 of the project, when procured.

Table 2.1: Project objectives established as part of Workshop 1 with Project Governance Group

Agreed objectives (this scope of works)	Responsibility
To identify feasible options for effective NBS across the catchment.	T+T Project Team
To prioritise NBS effectively within the catchment (taking a top – down catchment approach).	T+T Project Team
NBS will be site specific, with clear outcomes, and manageable sizes (i.e., small/medium solutions).	T+T Project Team
Tangata whenua values/sites will be integrated.	T+T Project Team
Possible Phase 2 Objectives (potential future scope of works)	
Multi-party delivery of NBS	Led by Council
Connecting the community to a catchment evidence base	Led by Council

Agreed objectives (this scope of works)	Responsibility
Understanding what the levers are for multi-party funding.	Led by Council
Showing landowners within the catchment what can be achieved.	Led by Council

2.1 Considerations

As part of the Toolbox design, Te Ao Māori perspectives and insights expressed by Iwi and hapū were considered where possible. A separate Te Ao Māori workstream was conducted alongside the Toolbox development to incorporate and weave mātauranga within the Toolbox. As a part of this scope of works and to better integrate these findings, a series of workshops were completed with Council and the Waimatā Governance Group. The Governance Group consisted of tangata whenua members from Rongowhakaata (representing Ngai Tawhiri hapū), Ngati Oneone, and Te Whanau a Iwi. It also included Council staff and the Waimatā Catchment Group.

The workshops were designed to build initial ideas of mātauranga, to weave as much into the Toolbox as early as possible. The workshops were also used to discuss findings, address limitations and deliberate future considerations.

Alongside this report, T+T are delivering an ArcGIS Pro Python toolbox, complete with spatial datasets and databases comprising the modelling and respective layers and inputs pertinent to the Waimatā catchment. In addition, other Python scripts necessary to process these datasets and perform model training and calibration are provided. A separate comprehensive Toolbox User Guide Manual document for these components is also included, to assist GDC in updating and applying the model tool framework to other catchments, detailing the process of creating the layers and giving guidelines for general and GIS-specific users, as well as expert inputs.

3 Context and background

3.1 Site details

The 61 km long Waimatā River is located to the north-east of Gisborne city. The Waimatā River drains an area of 370 km^2, and confluences with the Taraheru before forming Tūranganui River and discharging into Tūranganui-a-Kiwa/Poverty Bay (Figure 3.1). The river comprises steeply dissected valleys and terrace constrained floodplains, which essentially act as a flume, flushing flows, logs, and sediment through the system. During large storms, these factors contribute to ongoing slash, sediment and flooding issues throughout the catchment, affecting environmental, cultural, and recreational values and posing threats to property and infrastructure.

Weather events, such as cyclones Hale, Gabrielle and the storm of March 2022, have resulted in extensive morphological change throughout the Waimatā Catchment as slopes fail, channels erode, and floodplains accrete. The impacts of these large storms are often exacerbated by antecedent events which may create saturated conditions in the catchment.

Vulnerable to flooding and tropical cyclones, the river has seen land use changes such as forestry harvest and the conversion of mānuka scrub to pasture, increasing the catchments vulnerability to disturbance by extreme weather events. This impact is evident in the prevalence of standing pine in susceptible areas and large-scale landslides such as those associated with Cyclone Gabrielle, Cyclone Hale and the March 2022 storm, which, along with a temporary relief program for woody debris, have contributed to a reduction in the river’s flood capacity and accumulation of large woody debris in the channel network and valley floors. Routine removal of this debris represents a short-term solution to a long-term issue, which helps emphasise the need for a strategy for the future.

Figure 3.1: Waimatā Catchment and major tributaries.

3.2 Current geomorphology

Rivers on the East Cape of Aotearoa, New Zealand, including the Waimatā catchment experience some of the world's highest sediment yields due to its weak lithology, land use changes (forestry conversion/agriculture), and frequent high rainfall events (Marden et al., 2012). These factors have significantly altered the catchment's sensitivity and resilience, leading to widespread erosion and an increase in sediment delivery to the river mouth. Even while covered by forests, the catchment is prone to substantial erosion due to short-duration, high intensity rainfall events, particularly associated with cyclones.

Gullies, sheet wash, bank erosion, and landslides have dramatically shaped the landscape, and these erosive events cause occasional obstructions to infrastructure such as bridges and roads. The geomorphic processes operating throughout the catchment, coupled with the impact of land use practices, have resulted in ongoing sedimentation issues (see Photograph 3.1). The combination of sediment connectivity and transport in shaping the landscape is crucial; the Waimatā Catchment displays high longitudinal, lateral, and tributary confluence connectivity. This allows for the system to transport sediment efficiently through to the sea once it enters the main stream.

Photograph 3.1: Sandy drapes of sediment building up the floodplain of the Mangahouku Stream, a major tributary of the Waimatā (cf. Figure 1.1). (Source: Khendra Harvey).

The river acts (more or less) like a flume, rapidly delivering large quantities of sediment through the catchment to the coast. However, this process doesn't always occur smoothly; it could be compared to a 'jerky conveyor belt' in the sense that it delivers sediment in large pulses mostly derived from hillslope failures and bank erosion during storm events. The efficient sediment pathways of the Waimatā, constrained by terrace margins, leave little room to accommodate sediment and flows, often leading to frequent floodplain aggradation (see Appendix A). Wood accumulation, typically resulting from forestry slash or erosion of riparian planting, is a common occurrence and has the potential to cause significant infrastructural damage within the catchment. Efficient sediment and wood pathways are reflected in the distribution of River Styles across the Waimatā (Cullum et al., 2017). Whereby the main stem of the Waimatā flows through partly confined sections of terrace and bedrock margins, as indicated in the landcover, geology and topography Figure 3.2 below.

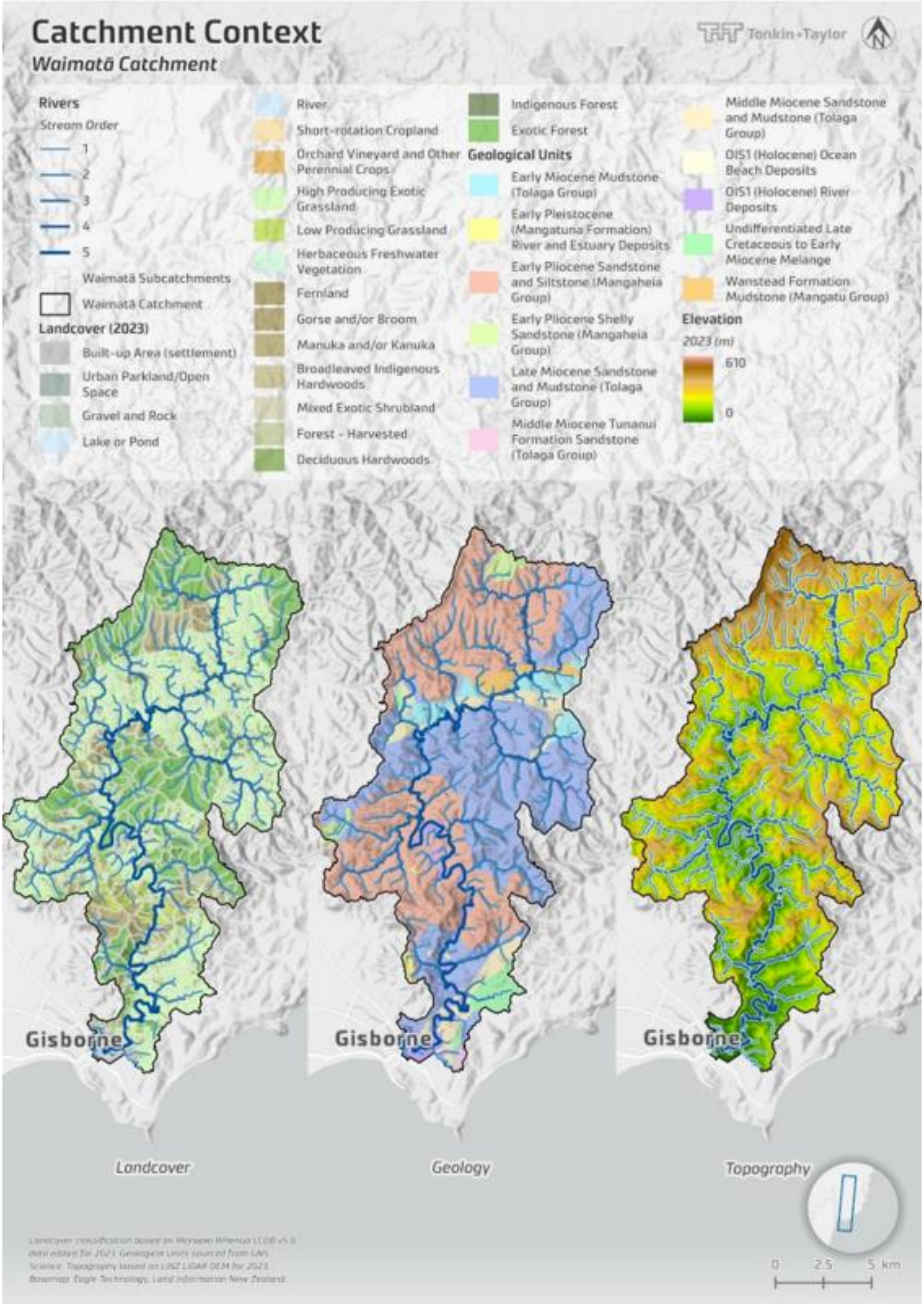


Figure 3.2: Landcover, geology and topography of the Waimatā Catchment.

3.3 Climate and cyclones (Gabrielle and Hale)

The East Cape, in particularly the Waimatā catchment experiences frequent landslides and flooding due to its vulnerability to cyclones, typically occurring between March and May (Cullum et al., 2017).

This region undergoes significant landscape changes and experiences fluctuating sediment volumes due to high rainfall.

Historical evidence indicates that climate variations during the Quaternary period played a significant role in shaping the landscapes we observe today (Newnham et al., 1999). One distinctive feature, the fluvial terraces that stretch along much of the river, have experienced continuous alterations (Berryman et al., 2000) and contribute to ongoing delivery of sediment/wood to Poverty Bay as they are subjected to erosion by adjacent river channels.

The fluctuations in both climate and sea levels during the Pleistocene epoch significantly influenced the relief, sediment dynamics and the terraces within the Waimatā region. During the Last Glacial Maximum, which was about 20,000 years ago, the sea level was approximately 120 m lower (Cullum et al., 2017). This resulted in varied incision rates, enabling the formation of floodplains, which were successively abandoned to form river terraces during incision episodes.

Periods of high incision led to increased erosion, steepening of hillslopes, and large deposits of sediment in valleys. Today, the footprints of these fluctuations are visible across the extent of the river – large terraces (Figure 3.3) with evident stratification and variable sediment characteristics are proof of this (Cullum et al, 2017).

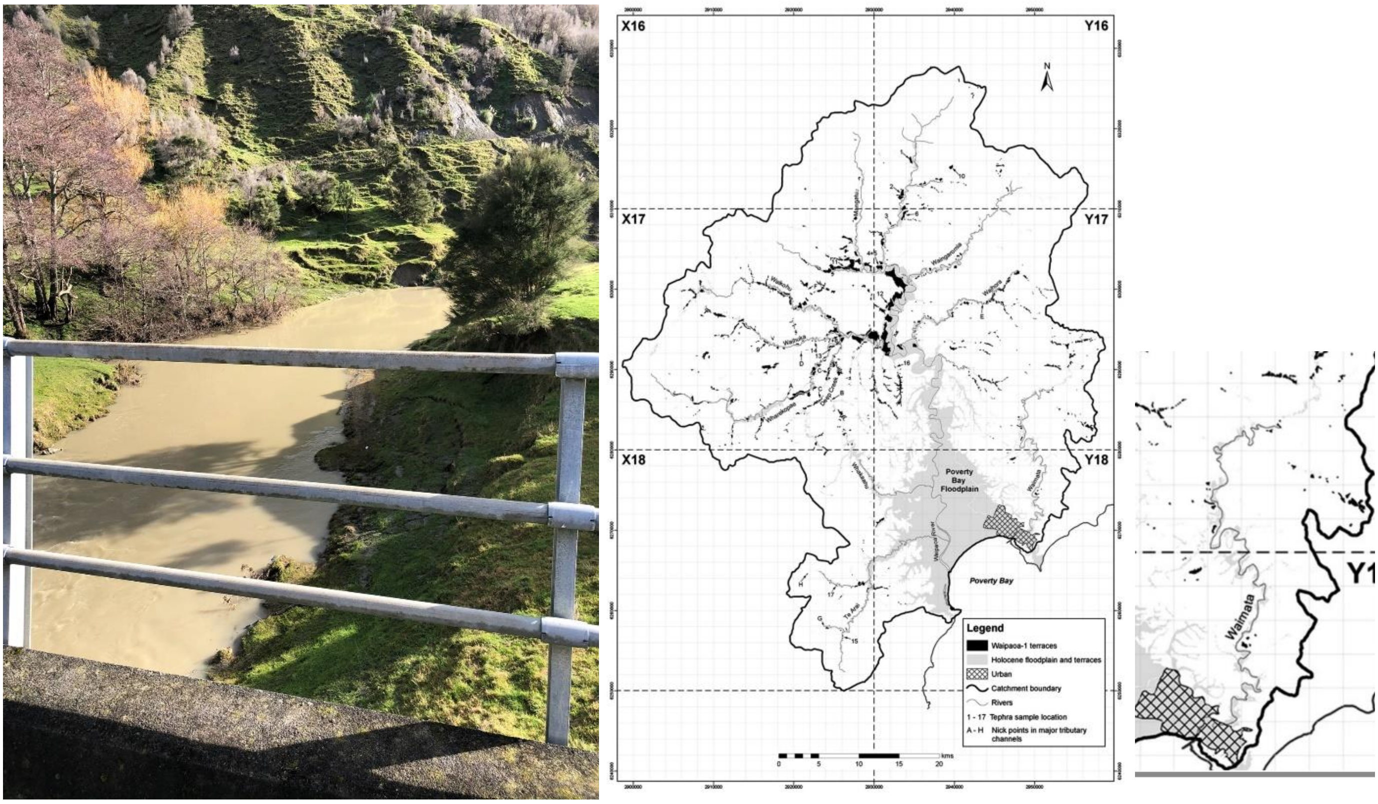


Figure 3.3: Holocene terraces confining the true right bank above Riverside Road Bridge (left). Mapped terraces of the Waipaoa and Waimatā Rivers showing the extent of Holocene terraces, resulting in terrace-confined river channels in the Waimatā (right). Source: Marden et al.(2008).

3.4 Geology and lithology

East coast rivers generate some of the highest sediment discharge globally due to its combination of weak lithology and heavy rainfalls (Marden et al., 2012). The Waimatā Catchment is predominantly made up of weak, easily erodible Paleogene sedimentary rocks, which include predominantly mudstone with some sections of alternating sandstone and mudstone (Figure 3.2). Its susceptibility to landslips is due to the presence of weak, unconsolidated soils found in its highly dissected steep headwater areas. In the mid-upper catchment, large volumes of tephra, originating from the Taupo Volcanic Zone, have been redistributed along the valley floors. The catchment also features pumiceous soils with low clay content, resulting in high macro porosity, deep rooting depths, but very low soil strength (Cullum et al., 2017). The appearance of distinct hummocky terrain in moderately sloped areas is a consequence of shallow earthflow activity induced by strata with smectite clay (Photograph 3.2).

Photograph 3.2: Shallow earthflows in Waimatā tributaries.

Historical climate and tectonic activities have had a significant influence on the Waimatā's topography, also contributing to high sediment yields[1]. The catchment sits within the margin of the Hikurangi subduction trench, experiencing uplift rates of up to 6 mm year-1 (Litchfield et al., 2020).

Recognising erosion processes and sediment sources in a catchment are essential to understand the sediment behaviour in the Waimatā, with fine-grained sedimentary rocks delivering more suspended load than bed load calibre material to the river. Furthermore, soils of the catchment contribute significantly to sediment generation. In areas with steep terrain, these weak soils combined with high slopes lead to high erosion rates, as well as mass bank failure.

3.5 Concepts

3.5.1 Sediment connectivity

Sediment connectivity is the connected transfer of sediment from one landscape unit to another. It describes the potential for sediment to be freely transported laterally, longitudinally, and vertically in a catchment. Sediment connectivity drives the river's ability to source and transfer sediment. Whereby, high lateral connectivity (including hillslope coupling) allows sediment to freely enter a channel, and high longitudinal connectivity means the channel is able to transport this sediment downstream, free of barriers, such as weirs, channel constrictions, debris jams or dams. Position within a catchment is a crucial control on sediment connectivity and transfer patterns, commonly termed the source, transfer and accumulation zones (Schumm, 1977) (Figure 3.4).

[1] NIWA NZ River Maps estimate 784,747 tonnes/year (Hicks et al., 2011).

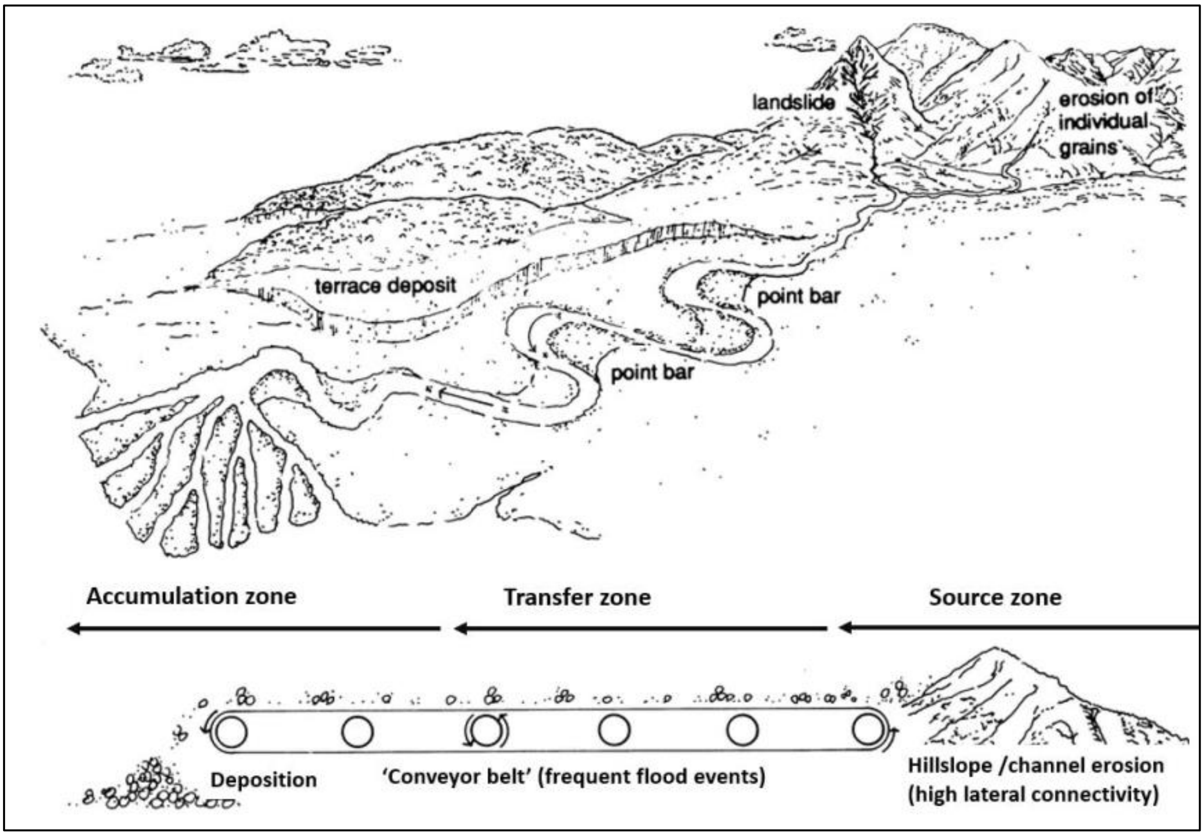


Figure 3.4: The conceptual source, transport and accumulation model used as the basis for the sediment connectivity patterns used in this report (modified from Kondolf, 1997).

Connectivity in the Waimatā varies throughout the catchment. Hillslope/channel connectivity is relatively low when alluvial fans, floodplains and wetlands and swamps act as buffers that disconnect sediment conveyance to the trunk stream (Fryirs et al., 2007; Fuller et al., 2023). However, terraces/hillslopes are generally directly coupled, resulting in high lateral connectivity (Fuller et al., 2023). There is limited storage and accommodation space along the Waimatā, arising from terrace constrained reaches. Therefore, if fine grained sediment enters the mainstem, there is limited opportunity for sediment storage, and reworking of contemporary sediment stores with the exception of transfer reaches (Harvey et al., 2021). Significant log accumulations on beaches and within transfer reaches from areas of plantation forestry during major storms attest to the high longitudinal connectivity of the Waimatā River. Ultimately, the Waimatā River acts as a flume, efficiently delivering sediment through the system. Sediment which enters the stream is almost guaranteed to be transported through the system, therefore trapping sediment at source, before it enters watercourses requires catchment wide management (Fuller et al., 2023).

3.5.2 Nature Based Solutions (NBS)

Nature Based Solutions are being increasingly used to reduce the risk of flooding, erosion and woody debris generation in rural areas. In fluvial settings, NBS aim to reduce flood risk by restoring, enhancing, or mimicking natural processes and functions related to hydraulics, morphology, and ecology. The key objectives of implementing NBS include capturing, retaining, and dispersing floodwaters using native vegetation to slow erosion and mitigate land loss, improving the connectivity of the watercourse with the floodplain to decrease the need for interventions like dredging, maintaining or restoring the sediment balance to preserve stream channel geomorphology and floodplains. Incorporating NBS into watershed planning and engineering not only helps in mitigating local and downstream flood impacts economically, but also offers co-benefits such as groundwater recharge, water quality improvement, biodiversity enhancement, improved aesthetics compared to conventional infrastructure, and opportunities for human health, welfare, and recreation.

Six NBS options were explored for the Waimatā Catchment to help alleviate flooding, sedimentation and woody debris accumulation. The chosen NBS have been outlined in Section 4.5, which details the methods to determine relevant NBS, limitations of the NBS, timeframes for effective maturity and expected design life.

4 Methodology

To build the Toolbox to meet the project objectives, a series of different inputs and processes were followed (Figure 4.1). This figure has been adapted from the original proposal to outline the process that has evolved through project development. This methodology section breaks each of these inputs down and gives a high-level overview of the process followed. Further details are provided in the accompanying Toolbox User Guide Manual document.

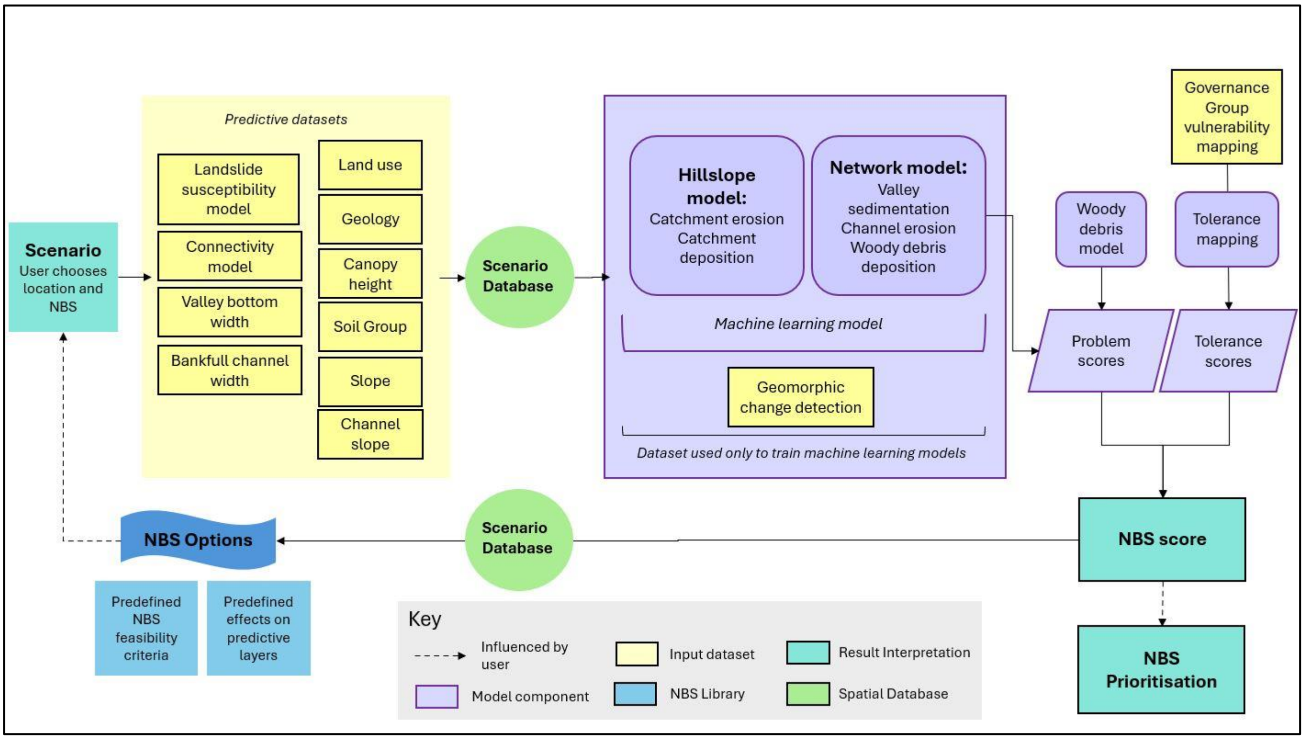


Figure 4.1: Model inputs and processes required for tool development.

4.1 Data collation

In the process of developing this Toolbox, T+T sourced catchment specific data to train and calibrate the models to the current conditions the Waimatā is experiencing. This includes a range of techniques to collate these base datasets, which are summarised in Table 4.1.

Table 4.1: Table of data sources for modelling

Model inputs	Data sources and limitations
Land Cover.	New Zealand Land Cover Database (LCDB)[2] and recent aerial imagery.
LiDAR DEM Surveys.	See LiDAR Surveys and Data Products section. The digital elevation model used in analyses other than the Geomorphic Change Detection was the most recent survey, in 2023.
Catchment Mapping: subcatchments, river network, valley bottom, bank full channel, river slope.	Digital elevation model (above) and recent aerial imagery.
Geomorphic Change Detection (GCD).	See Geomorphic Change Detection section.

[2] https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/

Model inputs	Data sources and limitations
Connectivity models.	High-resolution sediment connectivity model developed from the most recent Digital Elevation Model (above), and the Manaaki Whenua (Landcare Research) Landslide Susceptibility and Connectivity model[3] (see Section 3).
Soil permeability.	Fundamental Soil Layer Permeability Profile[4].
Canopy height and tree density.	Generated using point cloud data from the most recent LiDAR survey (above).
Geology.	NZ GNZ 250K Geological units (4th edition)[5].

4.1.1 LiDAR Surveys and Data Products

Light Detection and Ranging (LiDAR), is a remote sensing method that uses a pulsed laser to measure variable distances to the ground, as well as classifying above ground objects like trees, buildings, and even powerlines. LiDAR data sets were used as input in the GCD Software.

Table 4.2: LiDAR data sets used in model development

Dataset name	Metadata
Gisborne LiDAR 1 m DEM (2023)	Vertical datum: NZVD2016 Vertical accuracy specification is +/- 0.2 m (95 %) Horizontal accuracy specification is +/- 1.0 m (95 %)
Gisborne LiDAR 1 m DEM (2018-2020)	Vertical datum: NZVD2016 Vertical accuracy specification is +/- 0.2 m (95 %) Horizontal accuracy specification is +/- 1.0 m (95 %)

4.1.2 Geomorphic Change Detection

The Geomorphic Change Detection (GCD) software is part of the Riverscapes Consortium toolset for analysing fluvial environments, which detects topographic change. The GCD software is used to carry out topographic change detection in the Waimatā catchment. Volumetric change is calculated from the difference in surface elevations between DEMs derived from repeat topographic surveys – here the 2019/2020 and 2023 Regional LiDAR datasets.

4.1.2.1 GCD data inputs

GCD requires a set of inputs to detect topographic change in a catchment. As each DEM has an uncertain representation of the ground surface (which may vary in space and time), the key challenge is distinguishing actual geomorphic change from noise in the survey data. GCD quantifies those uncertainties independently in each DEM and propagates them through to the DEM of difference on a cell-by-cell basis. The GCD requires the following inputs:

- Slope (measured in degrees) – influences the uncertainty in elevation change due to terrain steepness.
- Point Cloud Density (measured in pulses/m^2) – influences the uncertainty in elevation change from the resolution and precision of LiDAR survey data. Minimum point cloud density for the New Zealand National Aerial LiDAR Base Specification is greater than 4 pls/m^2.

[3] https://www.arcgis.com/apps/instant/basic/index.html?appid=d382035d48a14e2e8d863a19f53746c1
[4] https://lris.scinfo.org.nz/layer/48105-fsl-permeability-profile/
[5] https://data.gns.cri.nz/metadata/srv/eng/catalog.search#/metadata/33f450d9-30bb-47f8-81c2-28f05d1abb7e

- Canopy Height (measured in m) – influences the uncertainty in elevation change due to vegetation interference in the LiDAR survey data. The GCD ignores areas where vegetation height exceeds 2 m, to most accurately capture true geomorphic change in the catchment.
- Wet Channel Delineation – the location of the wetted channel at the time of survey as standard LiDAR cannot effectively penetrate water. The GCD ignored in-channel geomorphic change, focusing only on the riverbank and the catchment itself.

4.2 Assessment framework and scoring

To assess and prioritise effective NBS options within the Waimatā catchment, an assessment framework has been developed, as illustrated in Figure 4.2. This framework considers the potential impact of the problem (erosion, sedimentation, and woody debris) and tolerance (the ability of an area to cope with the impact), which can be combined into an NBS score. NBS options will alter various model parameters that influence the scale of the problem and the tolerance of a subcatchment and therefore impact the NBS Scores. These scores are then used to help assess the impact of NBS options and prioritise where NBS could go within the catchment. Each component of the framework is described further in the section below.

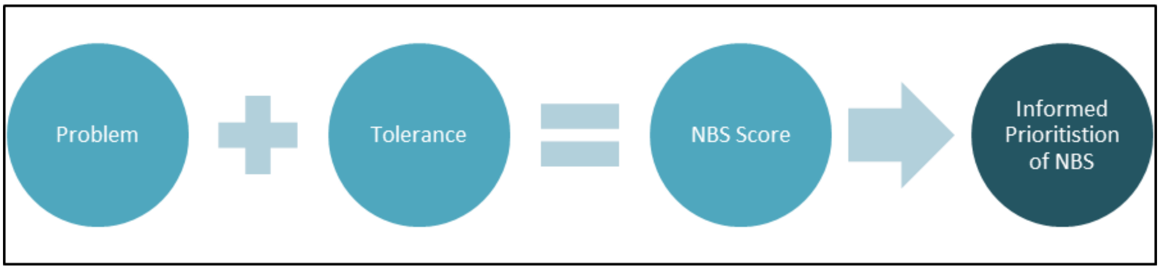


Figure 4.2: Assessment framework.

4.2.1 Problem

The 'Problem' categories for the purposes of this assessment, refers to the potential impacts experienced during Cyclone Gabrielle, and those that GDC want the NBS tool to reduce:

- Erosion on hillslopes.
- Sediment (both evacuated from the catchment and deposited on the valleys and stream network).
- Woody debris (evacuated from the catchment and deposited on the valleys and beyond).

These modelled impacts are the predicted result of extreme weather events and storms such as Cyclone Gabrielle and are the outputs of our modelling (i.e., the Machine Learning models detailed in Section 4.3.3 and the woody debris model described in Section 4.3.3.5).

The modelling output for each problem category listed above is a problem score for each subcatchment. This score reflects whether there is a reduction or increase in the potential impact of the problem because of a specified NBS implementation. It also represents the relative change of the potential impact, as compared with Cyclone Gabrielle. The problem scoring scale is presented in Table 4.3.

Table 4.3: Problem scoring

Problem scoring				
Low Impact	Mild Impact	Moderate impact	High Impact	Extreme Impact
1	2	3	4	5

Problem scores correspond to a particular scenario of NBS implementations. To assess the degree to which an NBS affects the problem, the Problem scores can be compared to a baseline case (where no NBS options are implemented). This comparison will allow relative improvements in Problem scores to be identified.

4.2.2 Tolerance

In the assessment framework, tolerance refers to a location's capacity to tolerate extreme weather events and storms. For example, areas where the river is known to deposit sediment were seen as areas that could tolerate or cope with the impact more than those where there are assets or elements of value, e.g., bridges or homes. The tolerance scoring is purely qualitative and based on the judgement of the Governance Group. A workshop was completed to establish tolerance scores for each impact category. This is further described in 4.4

The information collected in the workshop communicated less tolerance to deposition near bridges and in densely settled and developed areas, particularly near Gisborne. Where a subcatchment does not contain data from the Governance Group, an extrapolated tolerance score was developed for each subcatchment. This score takes into account the number of buildings, building density (count/km^2), and bridges.

It should be noted that geospatial layers that represent the built environment, e.g., lifeline utilities were not incorporated within the tolerance scores, as this level of detail was outside the scope of the Toolbox development. The methodology to include sites of cultural significance was explored but data was not made available to incorporate into the tolerance scoring. As outlined in Section 5.4.2, this is a potential area for toolkit extension.

Table 4.4 details tolerance scoring. A tolerance score of one reflects neutral tolerance, where the impact is not desired, but there may be some capacity of the subcatchment to cope with the problem. Conversely, a score of four represents a reach or subcatchment with a particular inability to cope or adapt to the impact, or where consequences would be high.

Table 4.4: Tolerance scoring

Tolerance			
High tolerance	Moderate tolerance	Some tolerance	Poor Tolerance
1	2	3	4

4.2.3 NBS Scoring

NBS Scores are given on a five-point scale for each subcatchment and are based on a combination of both the Problem and Tolerance scores. Table 4.5 presents the combined look up tables which represent how the scores are combined.

NBS scores correspond to a particular scenario of NBS implementations. To assess the effectiveness of an NBS, the NBS scores should be compared to a baseline case (where no NBS options are implemented). This comparison will allow relative improvements in NBS scores to be identified, corresponding to improved performance of the system under the NBS implementation.

It is important to note that the NBS scores do not capture all relevant considerations when understanding the implications of using various NBS options. The NBS scores focus on material outcomes in an extreme weather event, but do not model other relevant considerations such as environmental benefits, cost savings, community benefits, etc. Taking consideration of economic and social priorities in conjunction with the results of the Toolbox is necessary to properly appraise a plan for implementing NBS options.

Table 4.5: NBS Score Lookup table, giving NBS Scores for different combinations of Problem and Tolerance scores

		Tolerance			
	↘	1	2	3	4
Problem	1	1	1	2	3
	2	1	2	3	4
	3	2	3	4	5
	4	3	4	5	5
	5	4	5	5	5

4.3 Toolbox development

The Waimatā NBS Modeller Toolbox was developed using the Python programming language and the ArcGIS Pro Python Toolbox framework. The Toolbox was developed using industry-standard software development practices including automated testing.

Although the Toolbox has been developed with the Waimatā catchment as the immediate object of study, the software has been designed to accommodate modelling performed elsewhere.

The Toolbox has a relatively simple user interface and is intended to be accessible to a general GIS user, rather than solely GIS specialists. More details about the Toolbox, including details on how to use it, are provided in the Toolbox User Guide Manual document supplied alongside this report.

The Toolbox has been built to be compatible with at least ArcGIS Pro Version 3.2. Running the machine learning models requires a separate software package called uv[6] to be installed.

4.3.1 Other components

In addition to the Toolbox itself (which consists of a Python codebase and ArcGIS Pro toolbox file), there are several other relevant components, including:

- The Nature Based Solutions Modelling Map: the ArcGIS map space in which the Toolbox is accessed and run, where results and contextual datasets can be visualised, and where subsequent analysis tasks or map design can occur.
- Waimatā Sample Data:
  - Pre-processed input files.
  - Pre-trained machine learning and woody debris models.
  - Waimatā Contextual Data (such as delineated subcatchments, river segments and geomorphic change detection results).

[6] https://docs.astral.sh/uv/getting-started/installation/

- Assorted Python scripts for model development, data processing, data engineering and testing.
- Waimatā NBS Modelling toolkit.

4.3.2 Toolbox workflow

The Toolbox has 3 steps:

3 The relevant pre-processed input files and models for the studied catchment are input by the user:
   - For the Waimatā catchment, these will be provided together with the Toolbox for use in this step.
   - The models will run at this point to serve as a baseline against which the NBS options' effects can be compared.

4 A plan is specified for which NBS options are used, and in which subcatchments.

5 The models are run to calculate the NBS effects and to compare against the baseline.

4.3.3 Machine Learning methodology

The Machine Learning (ML) models are designed with a two-fold purpose:

1. To give insights into the impact of erosion and deposition under an extreme weather event in the Waimatā catchment, and how this is influenced by geospatially varying explanatory factors such as topography, hydrology, and land use.
2. To enable prediction of how erosion and deposition impact would change across a subcatchment when using different Nature Based Solution options through Problem scores.

4.3.3.1 Basic Machine Learning concepts and modelling strategy

4.3.3.1.1 Scale of modelling

There are 476 subcatchments in the Waimatā catchment. The ML models have not been trained directly on data at a subcatchment level due to the limited data points available – too few data points were available to train a machine learning model, which typically require many thousands of data points to be effective. Therefore, the Problem score has not been assigned at a subcatchment level, but instead, consideration has been given to the data at a 1 m x 1 m scale, which increases the number of data points to over 400 million.

4.3.3.1.2 Deep Learning is not used

Deep Learning is a type of machine learning that utilizes artificial neural networks with many layers - or "deep" networks - to model and understand complex patterns in datasets. Despite the large number of data points at a 1 m x 1 m scale, Deep Learning techniques are not appropriate for modelling this problem for a variety of reasons including:

- The strong geospatial component to the modelling problem.
- The limited number of input variables available.
- The necessity for interpretability of the models to allow for adequate review of the model behaviour to ensure it is appropriate for the purpose of using in the Toolbox.

For this reason, interpretable modelling approaches have been favoured.

4.3.3.1.3 Pros and Cons of using ML models

The main trade-off in the use of ML is between accuracy and interpretability. Using a simple qualitative assessment can be quite straightforward and interpretable but is not necessarily data driven. Using ML enables more complex relationships in the data to be accounted for, at the expense of decreased interpretability.

Interpretable modelling approaches have been adopted to try and mitigate the adverse effects on interpretability of the model. However, it must be acknowledged that ML models are inherently difficult to interpret, and an in-depth sensitivity analysis of the models has not been undertaken.

4.3.3.1.4 Categorical versus Continuous Variables

While some input data varies as a decimal number (for example, canopy height data varying in metres), other input data is *categorical*, in the sense that it does not correspond directly to a number but rather a qualitative fact. For example, the geology associated with a point is a categorical variable since it is not associated with a numerical scale or scientific unit – it is a category.

4.3.3.2 Input Datasets

The model was trained using the datasets shown in Table 4.6 associated with Cyclone Gabrielle. All datasets were rasterized and aligned on a 1 m scale between NZTM coordinate points 5707084N, 2033233E and 5735399N, 2048907E, i.e., with 28,315 rows and 15,674 columns of data. Scripts are provided to automate a similar process for other subcatchments.

Table 4.6: Input datasets used for training the Machine Learning models

<table>
<tr><th>Name</th><th>Description</th></tr>
<tr><td>Geology</td><td>A categorical variable corresponding to the geological unit. A high-level breakdown of values is given below.
<table>
<tr><th>Geology</th><th>Area (Ha)</th><th>Percentage of total</th></tr>
<tr><td>Early Pliocene sandstone and siltstone (Mangaheia Group)</td><td>9,148</td><td>41 %</td></tr>
<tr><td>Late Miocene sandstone and mudstone (Tolaga Group)</td><td>8,613</td><td>39 %</td></tr>
<tr><td><u>All Others</u></td><td>4,351</td><td>20 %</td></tr>
</table></td></tr>
<tr><td>Land Use</td><td>A categorical variable corresponding to the land use unit. A high-level breakdown of values is given below.
<table>
<tr><th>Land Use</th><th>Area (Ha)</th><th>Percentage</th></tr>
<tr><td>High producing exotic grassland</td><td>10,327</td><td>47 %</td></tr>
<tr><td>Exotic forest</td><td>5,710</td><td>26 %</td></tr>
<tr><td>Manuka and/or Kanuka</td><td>2,333</td><td>11 %</td></tr>
<tr><td><u>All Others</u></td><td>3,742</td><td>16 %</td></tr>
</table></td></tr>
<tr><td>MWLR Classification</td><td>A categorical variable giving the Manaaki Whenua (Landcare Research) Landslide Susceptibility and Connectivity model classifications.</td></tr>
</table>

Name	Description
Hillslope Classification	A True-False categorical variable designating whether the point is on the hillslopes, or whether it is on the valleys. This was mapped with a semi-automated methodology based on a vertical threshold approach, comparing the DEM against the elevation of the nearest river channel, with slope and topography-specific adjustments on a per subcatchment basis.
Canopy Height	The height of the foliage in **metres**, estimated using LiDAR as the difference between the DEM and DSM.
Connectivity	The runoff and sediment connectivity index I_c of Cavalli et al. (2013)[7] based on the work of Borelli et al. (2008)[8], derived from DEM. This value is **dimensionless**. Positive values correspond to a high connectivity. Since it is derived from the DEM, it only accounts for the effect of topography on sediment connectivity, and not other aspects.
Curvature	The sum of the second derivatives of the DEM surface at a 3 m scale, expressed as a percentage, and with the sign flipped, i.e., $$-100 \cdot \left[\frac{\partial^2 z}{\partial x^2} + \frac{\partial^2 z}{\partial y^2}\right].$$ This is in units of **%-per-metre** (i.e., decrease in % gradient per metre). A higher magnitude of curvature represents a rough ground surface with irregular slope at a 3 m scale. Positive values correspond to small dip in the topography, and Negative values correspond to a small mound. This is implemented by the *Curvature* tool in ArcGIS Pro.
Slope	The slope of the DEM surface in **degrees** at a 3 m scale.
Flow distance	The total flow distance in **metres** from the point to the river mouth at the bottom of the catchment.

4.3.3.3 Target Variable

The model quantifies erosion and deposition using GCD outputs. These outputs have units of metres and approximately correspond to the average ground movement across an area. Another interpretation is that they correspond to area-normalized erosion and deposition volumes in units of m^3/m^2.

When GCD outputs are negative there is erosion, and when the values are positive there is deposition.

It is important to note that the underlying methodology associated with the GCD algorithm does not give perfect estimates for erosion and deposition volumes, only a metric that is correlated with these. This makes it suitable to interpret as a measure of erosion and deposition impact but not as a precise predictor for actual volumes of material.

4.3.3.4 Modelling details

For more detailed information on the machine learning modelling and its validation, see the Waimatā NBS Toolbox User Guide Manual that accompanies the Toolbox. In brief:

- Regressors were trained for deposition and erosion separately.
- A standard geospatial block-based cross validation methodology was used to test the data in an unbiased way.
- Input data was aggregated into 50 m square cells to place the modelling problem at an appropriate geospatial scale.

[7] https://www.sciencedirect.com/science/article/abs/pii/S0169555X12002267
[8] https://www.sciencedirect.com/science/article/abs/pii/S0341816208000982

- Random Forest regressors were found to outperform other model architectures and so the final models are Random Forests (which are decision-tree based models and are very commonly the best performing models on medium-complexity datasets).
- Feature selection was performed to determine the most relevant predictive features to be included in the models

Residuals for the model are shown in below in Figure 4.3. These show how the model predicts compared to the GCD-derived values for erosion and deposition (measured as area-based rates in m^3/m^2). More detailed interpretation is given in the Toolbox User Guide Manual.

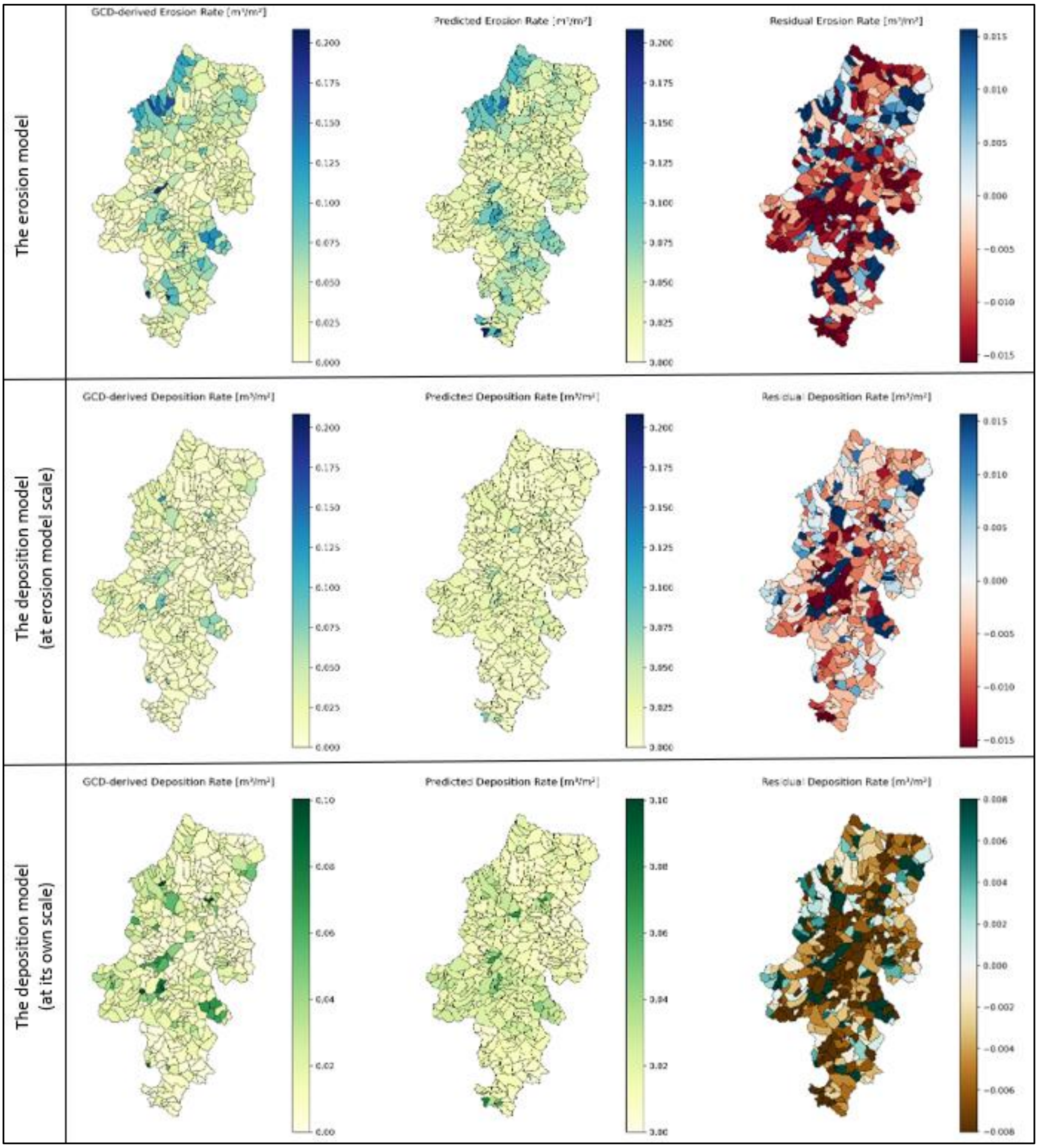


Figure 4.3: Model performance against training data.

4.3.3.5 Woody Debris model

A simple modelling methodology was adopted for woody debris in lieu of reliable quantitative data linking debris to its source subcatchment.

This methodology is detailed in the Toolbox User Guide Manual. In brief, area-normalized woody debris volumes are assigned based on land uses, and these volumes are multiplied by a likelihood rating based on the MWLR Landslide Susceptibility and Connectivity categorization. These give an overall *Woody Debris Potential* measure, in units of m^3/m^2, which can be de-normalized to give a volumetric potential.

Note that these potential measures do *not* correspond with the actual predicted volume of woody debris. They measure the *potential* for woody debris exported from each subcatchment.

4.3.3.6 Assignment of Problem scores

Based on the predictions of the different model components, for each subcatchment, it is possible to calculate:

- The erosion rate (m^3/m^2) on hillslopes.
- The total accumulated upstream sediment volumes exported through the valleys including contributions from the hillslopes (in m^3).
- The total accumulated upstream woody debris potential (in m^3).

Based on these, equal-width histogram bins can be assigned to the data associated with the status quo, i.e., with no NBS rules applied. The top 5 % of hillslope erosion rates and top 15 % of total accumulated volumes are outlying and are excluded for the bin-size calculation to avoid disproportionate influence on the bin widths. These histograms and associated Problem scores are shown in Figure 4.4, Figure 4.5, and Figure 4.6. Values are rounded to one significant figure to reflect the semi-quantitative nature of this assignment methodology. The values are given in Table 4.7.

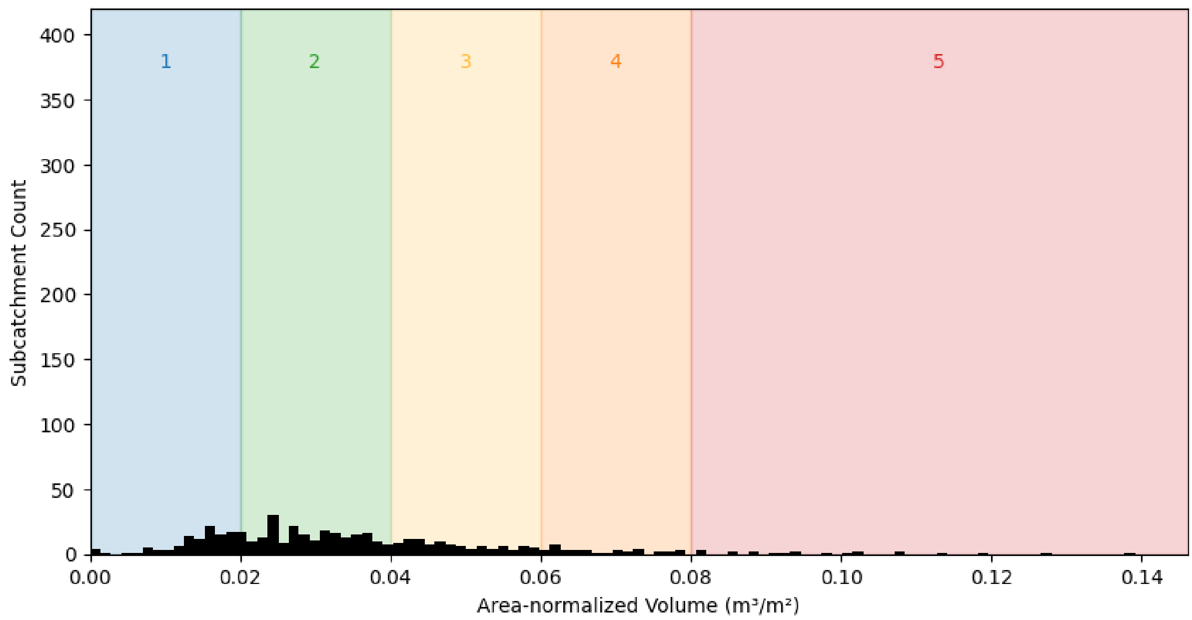


Figure 4.4: The area-normalized hillslope erosion volumes for each subcatchment, with assigned Problem scores annotated.

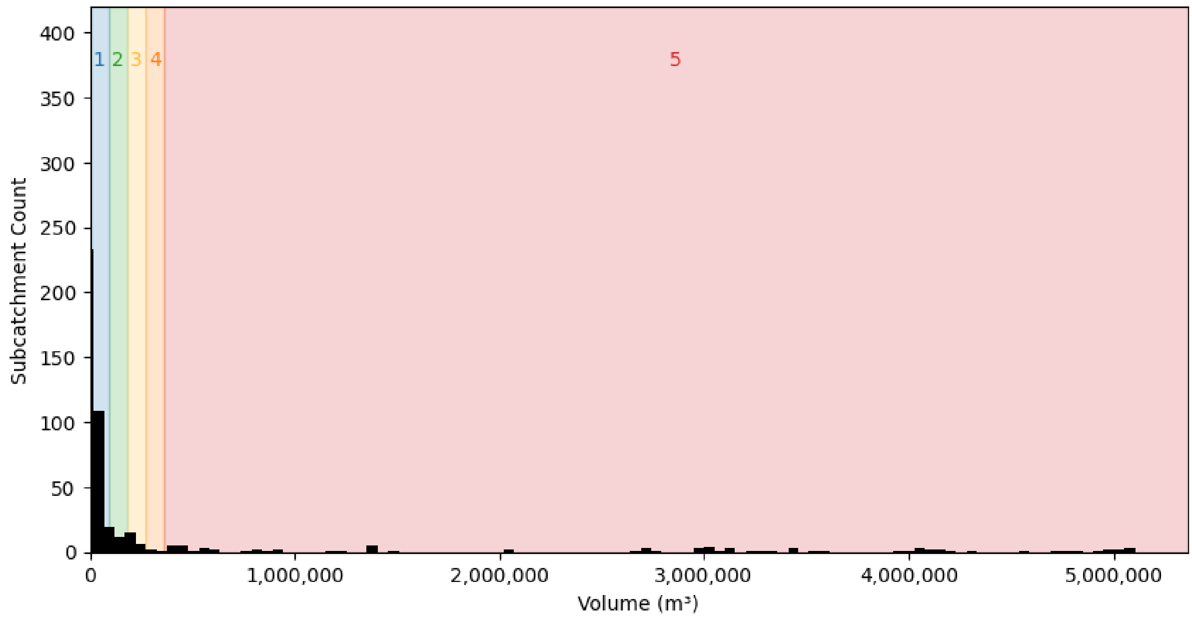


Figure 4.5: The total accumulated upstream sediment volumes for each subcatchment, with assigned Problem scores annotated.

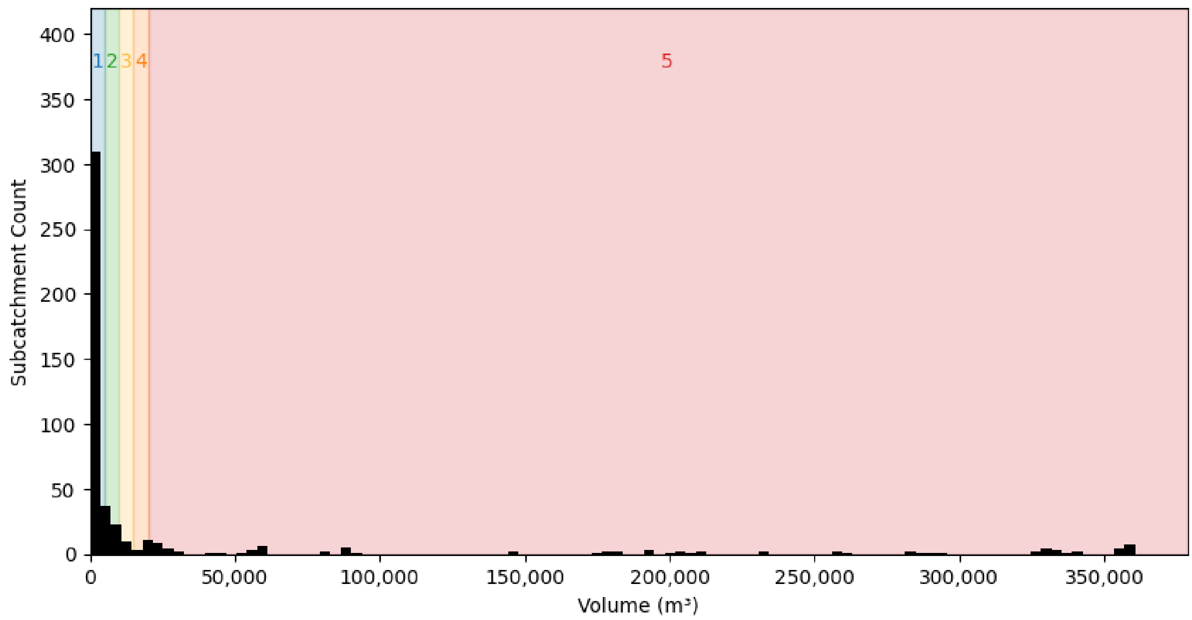


Figure 4.6: The total upstream accumulated Woody Debris Potential for each subcatchment, with assigned Problem scores annotated.

Table 4.7: Assigned Problem scores for different problem aspects

	Problem Scores				
	1	2	3	4	5
Area-normalized erosion on hillslopes (m^3/m^2)	0 – 0.02	0.02 – 0.04	0.04 – 0.06	0.06 – 0.08	>0.08
Total accumulated upstream sediment (m^3)	0 – 90,000	90,000 – 180,000	180,000 – 270,000	270,000 – 360,000	>360,000
Total accumulated upstream Woody Debris Potential (m^3)	0 – 5,000	5,000–10,000	10,000–15,000	15,000–20,000	>20,000

4.3.3.6.1 Overall Problem score

The three problem aspects shown in Table 4.7 give three separate Problem scores. These need to be combined together into a single Problem score. A lookup table for this purpose is given in Table 4.8.

Table 4.8: Lookup giving overall Problem score based on three separate problem scores for the different problem aspects

Total accumulated upstream Sediment Problem Score	Total accumulated upstream Woody Debris Potential Problem Score	Hillslope Erosion Problem Score				
		1	2	3	4	5
1	1	1	1	1	1	2
1	2	1	2	2	2	3
1	3	1	2	3	3	4
1	4	1	2	3	4	5
1	5	2	3	4	5	5
2	1	1	2	2	2	3
2	2	2	2	2	3	3
2	3	2	2	3	4	4
2	4	2	3	4	4	5
2	5	3	3	4	5	5
3	1	1	2	3	3	4
3	2	2	2	3	4	4
3	3	3	3	3	4	4
3	4	3	4	4	4	5
3	5	4	4	4	5	5
4	1	1	2	3	4	5
4	2	2	3	4	4	5
4	3	3	4	4	4	5
4	4	4	4	4	4	5
4	5	5	5	5	5	5
5	1	2	3	4	5	5
5	2	3	3	4	5	5
5	3	4	4	4	5	5
5	4	5	5	5	5	5
5	5	5	5	5	5	5

4.4 Engagement

A series of workshops was undertaken across the course of this project. These workshops were held with the project Governance Group which consists of:

- Tangata whenua members from Rongowhakaata (representing Ngai Tawhiri hapu), Ngati Oneone, and Te Whanau a Iwi.
- Council staff (Land Management Team, Hydrologists, Geomorphologists, River Mangers).
- Waimatā Catchment Group (including landowners).

It was of importance to the Governance Group that a Te Ao Māori lens was incorporated within the Toolbox to further understand and prioritise areas for interventions. A separate Te Ao Māori workstream was completed alongside this project. However, the findings of this work were not completed prior to the Toolbox being developed so were not included in the 'tolerance' scoring system. Mātauranga that was shared during the workshops was incorporated where possible.

To ensure the knowledge and views of the Governance Group were incorporated into the process and Toolbox, three workshops were held both in-person and online. Each of these workshops had a different purpose and outcome, as detailed in Table 4.9. Ideally the engagement process followed for this catchment would be completed for any future catchments GDC want to explore.

Table 4.9: Engagement approach

Workshop	Purpose and outcomes	Agenda/activities	Outcome
1 (in-person, 4 hours)	• Establish connections between Governance Group and T+T. • Confirm project and Governance Group principles. • Defining what Nature Based Solutions are. • Establishing and confirming project and Governance Group objectives. •	• Introductions. • Purpose and objectives – understanding what the Governance Group need out of the project and the workshops. • Project Overview – defining NBS and giving context to the Waimatā Catchment. • Brainstorm – what do you need from this project? What do you want the Toolbox to do? How do we measure success? • Catchment Activity – mapped out key areas of damage from Cyclone Gabrielle, key network routes, landowners, forestry rotations etc. • Overview of the workshop and reflecting on confirmed objectives.	• Project objectives as confirmed by the Governance Group. • Possible Phase 2 objectives (as the Toolbox moves into implementation). • Governance Group given context around NBS and further knowledge of the catchment. • Mapping exercise outputs.
2 (online, 2 hours)	• To establish and confirm tolerance scores across the catchment for: – Flooding. – Sedimentation. – Erosion. – Woody debris.	• Purpose and objectives – both for project and workshop. • Key terminology and examples. • Tolerance Mapping – across the catchment using online digital tool. • Overview of shortlisted NBS for the Waimatā Catchment.	• Mapped tolerance across the catchment for each of the areas. • Updated NBS options list with feedback from Governance Group.

Workshop	Purpose and outcomes	Agenda/activities	Outcome

3 (in-person, 4 hours)	• To share the journey of the Toolbox development to date.
	• To support the development of an outline communications plan that seeks to understand:
	  • Who needs to be engaged with and why?
	  • What information needs to be communicated to each of the identified groups?
	  • How should this be communicated (i.e., existing forums/other mediums).
		• Purpose and objectives – both for project and workshop.
		• Assessment framework updates – changes to terminology (problem, tolerance and NBS score).
		• Toolbox development journey – to highlight the evolution of the Toolbox and the data constraints.
		• Who needs to be engaged and why? – Using a power/influence matrix identify the key stakeholders for the Toolbox journey.
		• How will they be communicated with? – Discuss how each of these groups will be communicated with, e.g., through existing engagement, emails, websites etc.
		• What information is to be communicated? – What aspects of the Toolbox journey need to be communicated with each group.
			• Outline communications plan.

4.5 NBS Options

A series of NBS options was explored to incorporate into the model. NBS options were established based on those outlined in Griffiths et al. (2024), Bridges et al. (2021) and guidelines which outlined approaches to reducing sediment and woody debris, such as the NES-CF (2023). Table 4.10 details the chosen options to incorporate into the model and highlight the relative high level costing implications, establishment timeframes, potential locations and scenarios to be included in the modelling.

High level costing has been included for each of the NBS options, based on a relative scale, with $$$ being a relatively high cost NBS option and $ being a relatively low-cost option. High cost NBS options are likely to incorporate multiple components to install. For example, retirement and revegetation of permanent forest is likely to include (but not limited to) the following costs:

- Retirement of productive land, this could include beef/sheep farming, horticulture and forestry.
- The cost of buying the correct native/exotic forest cover.
- Costs associated with planning and consenting (e.g., planting plans, ecology assessments etc.).
- Ongoing maintenance costs during window of erosive vulnerability.

A relatively low cost NBS option, such as debris traps may include higher initial costs but are often one-time costs to install and design. However, it is important to consider ongoing maintenance costs for NBS options which act to trap or collect sediment and slash. However, it is important to note that a detailed cost benefit analysis will likely be required to feed into the feasibility of each of these NBS.

Establishment timeframes consider the minimum time these NBS options are likely to perform at their intended design capacity. For example, afforestation of permanent forest cover with slow growing natives is not likely to reduce sediment and flow runoff until it is established, with root systems to bind the soil and canopy cover to intercept rainfall. For example, Phillips et al. (2024) claims that following clear-cut forest harvesting, the time for root reinforcement to become effective at reducing rainfall-induced landslides is at least six years (Figure 4.7).

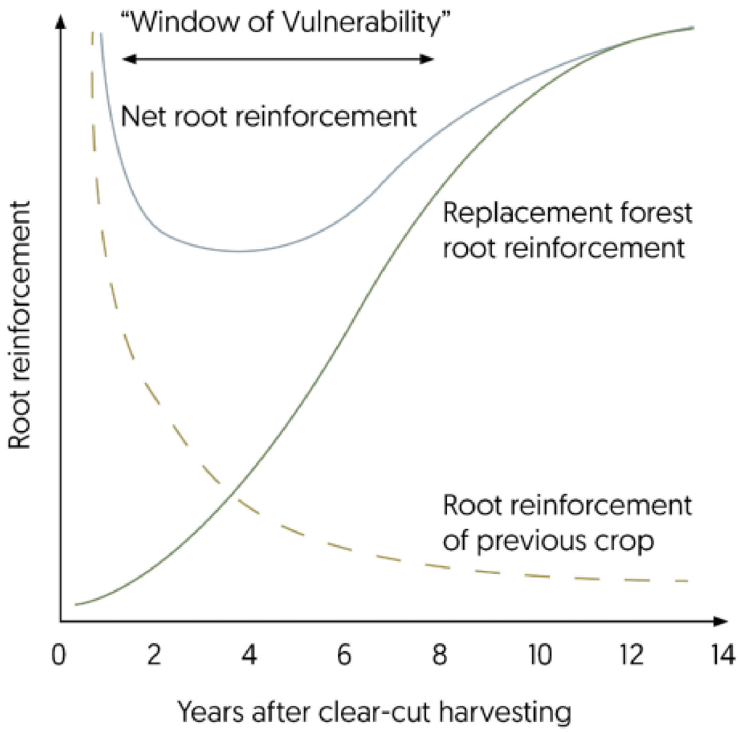


Fig. 1. 'Window of vulnerability'; a period following forest removal when steep land is vulnerable to rainfall-induced landslides (Phillips and Watson, 1994 modified from O'Loughlin, 1985 and Sidle, 2005).

Figure 4.7: Window of vulnerability from Phillips et al. (2024).

A spatial map layer of potential locations in the catchment where these NBS options are considered feasible serves to inform both the user of the Toolbox and the machine learning models themselves on where it is appropriate to apply changes from a given NBS. These areas have been delineated by geospatial selection analysis using the feasibility criteria in Table 4.10. For example, riparian planting strips can occur in locations with sufficient valley bottom width and have different magnitude of effect depending on the available area.

Additionally, sample scenario results aim to demonstrate which subcatchments are likely to be more effective at providing improving issues of erosion, sediment, and woody debris, relative to the catchment-wide modelled results. Re-establishing permanent forest cover is likely to benefit the whole catchment, since it is likely to have the greatest impact on reducing sediment erosion (and tangentially runoff) in steep areas which are prone to rainfall-induced landsliding.

Table 4.10: NBS options and their respective benefits at improving erosion potential, run-off and woody debris

NBS	NBS Subcategory	Benefits					Logistics		
		Purpose	Woody debris	Erosion	Flow reduction	Co benefits	Time frames	Cost potential	Locations
Afforestation	Agroforestry mixed low density.	• Conversion of agricultural land to low density agroforest.	• N/A.	• May provide some hillslope stability.	• Can aid rainfall interception.	• Retains productive land. • Provides shelter for stock.	10+ years	$	• Existing agricultural land. • Steep/landslide prone farmland.
	Dense native bush.	• Conversion of existing agricultural land and plantation forest to dense permanent bush cover.	• Reduction in slash generation. • Aids in trapping wood.	• New root systems acting to increase soil stability. • Reduces sediment connectivity by adding roughness and buffers to sediment flow.	• Reduction in stream power. • Aids in intercepting rainfall.	• Increases stream shading. • Improves fish habitat by reducing turbidity and water temperature. • Biodiversity. • Improves soil health.	50+ years	$$$	• Agricultural land. • Plantation forest. • Erosion prone steep hill sloped catchments.
Riparian planting	Narrow. Wide.	• Both aim to increase the riparian corridor on tributaries where valley widths allow.	• Can buffer woody debris entering the network.	• Prevents bank erosion and incision by increasing roughness, and limits sediment entering the stream from adjacent hillslopes by acting as a buffer. • It can reduce bank erosion by deterring stock trampling in banks and wading in channels.	• Help slow flows entering the stream through increasing land cover roughness. • Impact (reduction in flood peaks) is likely to be limited, as will not significantly reduce runoff or increase storage. • Likely local impacts on flood reduction, such as debris straining, deflecting flows/keeping more water in-channel, which may provide local benefits but are not expected to significantly impact the downstream hydrograph. • Scale of planting is unlikely to provide significant hydrological benefits such as reduction in runoff.	• Improve aquatic and terrestrial habitats through contributing large woody debris and providing shade for aquatic fauna. • It promotes bird life and restores biodiversity in stream environments. • Improved water quality by filtering out contaminants and sediment entering the river, stabilising/reducing water temperatures, and reducing erosion.	10+ years	$	• To be located along appropriately sized corridors determined by valley width and catchment size.
Floodplain retention/detention storage	Small scale. Medium scale. Large scale.	• Implementation of online wetlands/ponds to trap flow/sediment.	• Potential to trap woody debris.	• Retention storage traps and stores fine-grained sediments, preventing them from being delivered to the main stem from smaller tributaries. • Slowing fine grained sediment transport, which mimics natural functions of woody debris and other roughness elements.	• Small retention storage, including ponds, wetlands, and bio-swales adjacent to river channels on floodplains, capture and store rainwater or runoff, thereby reducing the volume of water that rapidly enters the larger water system during storms (detention). • Detention storage typically releases water slowly over a longer period, smoothing out peak flow in water bodies that usually leads to floods. • Storage enhances groundwater absorption ability. Can slow	• Re-establishment of wetland habitats which can increase biodiversity. • Potential to create recreational areas and native species conservation. • Reducing fine grained sediments helps improve aquatic habitats.	20+ years	$$-$$$	• Natural depressions, previous river courses, appropriately sloped area, floodplain.

NBS	NBS Subcategory	Benefits					Logistics		
		Purpose	Woody debris	Erosion	Flow reduction	Co benefits	Time frames	Cost potential	Locations
					tributary inputs into the mainstream which helps to reduce the flood peak. • Can increase flood capacity by increasing flood plain interaction to disperse flows and reduce stream powers.				
Other	Linear vegetative debris belts.	• Aimed to trap slash and buffer sediment before entering a stream network.	• Can act as a buffer or barrier to trap LWD from hillslopes.	• Can act to trap sediment in strategic locations.	• N/A.	• Can provide shade for stock. • Can provide some habitat for terrestrial fauna.	10+ years	$	• Can be used on slopes adjacent or parallel tributaries/main stem.
	Debris traps.	• Aimed to capture large objects, such as slash and preventing it from exiting a catchment during flood flow conditions.	• Aims to trap majority of LWD before entering main stem.	• Can act to trap sediment in strategic locations.	• N/A.	• N/A.	Immediate	$-$$	• These traps are frequently implemented in high-risk river catchments during and after harvest to control downstream movement of slash originating from production forest.

Model parameters for NBS options are presented in Table 4.11.

Table 4.11: Model parameters for NBS options

NBS	NBS Subcategory	Modelling assumptions	Feasible locations	Justification
Afforestation	Agroforestry mixed use low density.	It is assumed that a small % of the area which is grassland will become permanent indigenous forest (assumed <10 % for the purpose of this analysis). It assumed that a small % of the area which has low canopy height will become high canopy height (<10 % assumed for this assessment). It is assumed that <10 % conversion to indigenous forest cover to be implemented in areas which the model determines will have the greatest benefit from afforestation. E.g., <10 % of cover will be prioritised in hillslopes which had erosion during Cyclone Gabrielle.	Only feasible on existing grassland. To be implemented at the catchment scale rather than a buffer from the stream or based on the Manaaki Whenua 3B layer.	We have adopted a 5 % coverage (based on literature - the Blashke et al. 2008) to avoid a negative impact on productive land capacity, which is defined by land use classes that are not already indigenous forest or established forest.
	Dense native bush.	Aims to convert specific land types to 100 % of modelled area to dense permanent bush. Broadleaf vegetation will be reliant on Mānuka/Kānuka taking a hold, therefore natural succession rather than direct planting is preferred. Planting composition (species/density) to be targeted to the terrain and impact you are wanting to lessen (to be determined in design and has not been implemented into this Toolbox).	Feasible existing land use types, including grassland, exotic forest (e.g., pine), as well as Mānuka/Kānuka stands.	Conversion of 100 % catchment to native bush seen to have 30-100 % reduction in sediment yield (Blashke et al., 2008). Reduction in peak flow dependent on subcatchment conditions, but at least 5 % reduction as per Blashke et al. (2008).

NBS	NBS Subcategory	Modelling assumptions	Feasible locations	Justification
Riparian planting	Narrow.	We have assumed that allowing for a riparian buffer zone will act as a buffer for sediment connectivity. Success of riparian planting determined by the assemblage of planting and appropriate vegetation management (fencing/pest control/weeding).	Only feasible in environments which are able to support riparian planting. Valley bottom areas greater than 5 m in width. Adjacent to streams with less than 3m entrenchment. Eliminate high risk erosion and aggradation areas by excluding upper and lower quantile of GCD (erosion/deposition).	Topographic constraints of the Waimatā lead to challenges in establishing appropriate riparian zones. Criteria have been based from Griffiths et al. (2024) and Forbes et al. (2018). Entrenchment threshold based on Rosgen (1996) and adjusted for the Waimatā catchment, used to ensure the accessibility of valley floor to flood flows.
	Wide.	We have assumed that allowing for a wide riparian buffer strip will decrease sediment connectivity. Landscape scale pest control will likely be key to any reversion of riparian planting.	Only feasible in environments which are able to support riparian planting. Valley bottom areas greater than 10 m in width. Adjacent to streams with less than 3 m entrenchment. Eliminate high risk erosion and aggradation areas by excluding upper and lower quantile of GCD (erosion/deposition).	
Other	Linear vegetative debris belts.	Aims to reduce connectivity in the most connected areas by implementing a vegetative barrier near the toe of hill slopes above streams to impede sediment and woody debris.	To be located on floodplains greater than 2 m in width, adjacent to stream of any order. Cannot be placed on urban, gravel/rock or water.	Location and effectiveness of vegetative debris belt have been informed by from a high-level review from Easdale (2021).
	Debris traps.	In-stream woody debris reduction estimated to be 90 % following the installation of debris traps.	To be located on smaller tributaries within forestry catchments in stream orders 1-3.	Likely to capture most of the woody debris within the catchment if the trap is installed within a choke point at the bottom of the catchment. However, there has been a 10 % buffer added to account for uncertainty.

NBS	NBS Subcategory	Modelling assumptions	Feasible locations	Justification
Retention/ detention storage devices	Small scale.	Small level of effectiveness (low trapping efficiency) where there is enough land to accommodate storage at 2 % of catchment area.	Not located in indigenous forest, and with sufficient area with appropriate slope to accommodate a wetland. Geospatial suitability analysis undertaken to define locations to test for feasibility. This included: • Stream orders 1-3. • Natural basins and sinks. • Lowest 25 % of subcatchment elevation. • Slope below 15 degrees.	Sediment trapping effectiveness derived from benchmarks outlines in Smith & Muirhead (2024).
	Medium scale	Medium level of effectiveness (moderate trapping efficiency) where there is enough land to accommodate storage at 3 % of catchment area.		
	Large scale	Most effective where there is enough land to accommodate storage at 5 % of catchment area. High trapping efficiency.		

5 Interpretation

5.1 Model result interpretation

Running modelling scenarios by implementing NBS at considered and strategic locations allows for greater insight into where and how NBS might be used to mitigate the damaging effects of erosion and deposition in storm events. As more scenarios are tested, and a collection of results is visualised and explored in the map space, the Toolbox facilitates prioritisation of NBS planning efforts by comparing NBS scores for different NBS strategies/scenarios.

While NBS scores are at the subcatchment level, some NBS options may affect the entire downstream catchment. When applying a given NBS to a subcatchment, the Toolbox uses the feasibility criteria and modelling assumptions detailed in Table 4.5 to change the predictor variables for the model, so running a new prediction for that scenario estimates the impact of that NBS in the catchment and in the downstream network. For example, by modelling a scenario where riparian planting is installed in subcatchment A, and a small-scale retention storage basin is installed in subcatchment B, the results will show relative change in erosion and deposition in subcatchments A, B and C (assuming a simplistic flow direction of A to B to C). It is likely that some NBS may be found to have negligible effect, producing results that show no change to the NBS scores in the subcatchment or downstream. Similarly, it is possible for NBS options to make things worse in some cases. The trade-offs are sometimes counter intuitive, e.g., planting trees can decrease erosion and sediment export but increase woody debris potential. It is important to note that this is a valid model result that should be considered as part of NBS option prioritisation.

Figure 5.1 shows an example scenario where the dense native bush NBS is applied catchment wide. By comparing the NBS scores of the unmodified base case predictions with the scores resulting from that broad-scale modification, reductions in NBS score are observable. In some locations, an increase in score occurs, because of the elevation of woody debris risk associated with increased canopy heights and tree density. Using the supplied map space in ArcGIS Pro, more detailed interrogation of these datasets is enabled.

This is a simplistic example to illustrate the Toolbox results. In practice, users may model more complex scenarios that include multiple NBS in specific locations to understand the estimated effects of a more bespoke NBS strategy.

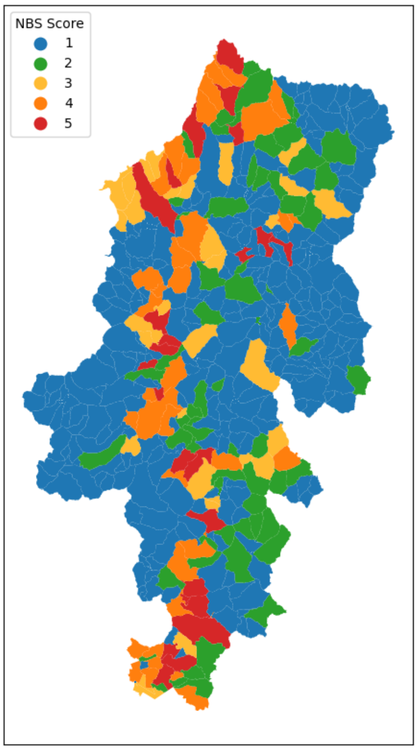
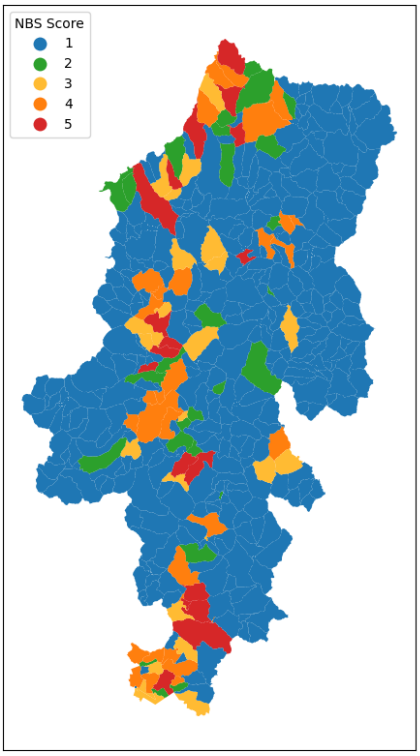
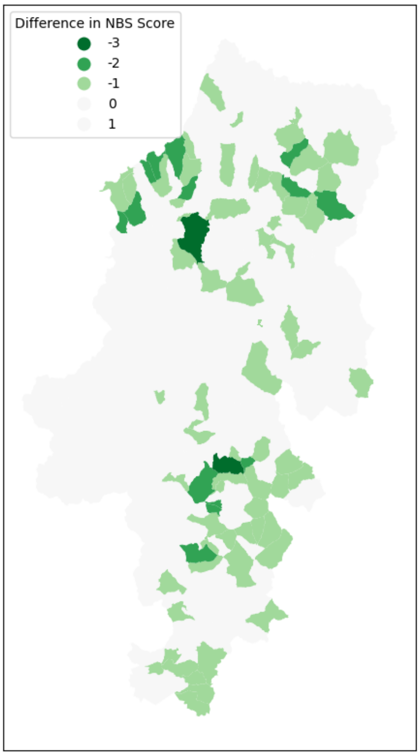
Base case	Dense native bush	Difference
		

Figure 5.1: A comparison of NBS modelling scenario results implementing dense native bush.

5.2 Model interpretation applicability

The results of the NBS Scenario Modelling Toolbox need to be understood and interpreted in the correct context to enable decision making that is appropriate and impactful. Being a data-driven Toolbox, the resolution of the results is dependent on the resolution of the input datasets. For example, the +/- 0.2 m vertical accuracy uncertainty in each LiDAR survey can be expected to propagate through any subsequent modelling. However, by using sequential LiDAR surveys (amongst other datasets) to create a model that predicts erosion and deposition as well as the effects of NBS, this Toolbox provides an ability to gain insight into how NBS might allow for a relative reduction in problematic erosion and deposition in a storm event.

Ultimately, the Toolbox uses available datasets to provide unique but incomplete perspective into catchment management and restoration opportunities. Therefore, the Toolbox results should be interpreted in conjunction with empirical experience and indigenous knowledge about the catchment.

The machine learning models are trained on the real geomorphic change experienced in the Waimatā catchment between 2019 and 2023. This is used to predict a base case – a model prediction of the period. Importantly, the modelled impacts of implemented NBS in each scenario are relative not to the GCD-derived ‘reality’ but to the base case as predicted by the model. The impacts of a modelled NBS scenario should first be compared to the predicted base case, before comparison to the results of other scenarios.

While the results of the Toolbox do include the modelled volumes of erosion and deposition (in m^3/m^2), it is not appropriate to view these figures as deterministic or accurate predictions of what might happen in a different storm event. As such, the methodology for classifying subcatchment risk scores along with tolerance scores, aggregates and sorts the raw model results into something more useful for decision making. Experimentation is necessary because there are many combinations of possible NBS.

5.3 Limitations

With any tool, it is crucial to understand and acknowledge the uses, constraints and limitations:

- The Toolbox should be used as an initial guide to inform potential NBS options for GDC to investigate within the Waimatā Catchment. The toolbox will provide the user with high level NBS options in locations around the catchment and will output relative effectiveness of those NBS options in relation to mitigating sedimentation, erosion, and woody debris effects.
- NBS options tend to be more effective during smaller magnitude (more frequent) storm events and within a localised area. The relative effect of a discrete NBS option may appear less significant in the model (which is trained using the high magnitude, low frequency Cyclone Gabrielle event), when compared with its potential effect in an event smaller than Cyclone Gabrielle, and in a localised downstream area.
- The models included in the Toolbox have been specifically trained on the Waimatā Catchment. Additional model training and calibration tool approaches are provided in the Toolbox User Guide Manual, together with the Toolbox, to assist GDC with implementation in other catchments. It must be acknowledged however, that this aspect is not included in the Toolbox itself, so re-application to a different catchment will require knowledge of the Python programming language and Data Science and GIS expertise. In addition, appropriate data inputs need to be established for new catchments such as Geomorphic Change Detection (GCD) analysis, and tolerance mapping.
- The Toolbox is data-driven; therefore, the output quality is dependent on the input quality. The Toolbox uses the data and information available at the time the project was undertaken, however there are likely to be opportunities to re-train and re-calibrate the model using higher quality and/or more up-to-date data in the future.
- The Toolbox has been developed using a semi-quantitative approach and considers the effect of NBS in comparison to a Cyclone Gabrielle sized event. The Toolbox models involve quantitative estimates for event impact and qualitative estimates for tolerance which are combined using a qualitative scoring framework to give NBS scores that can be used for prioritisation. Other detailed information regarding economic, social and cultural considerations should be used in conjunction with the outputs of the NBS Toolbox.
- A hydrological model was not incorporated within the spatial tool given the associated uncertainty with a simplistic runoff estimation approach and to avoid inconsistency with other more detailed hydraulic modelling efforts in progress across Tairawhiti and in this specific catchment. This should not be taken to imply that flooding is not an important consideration and detailed hydraulic modelling data could be included in future updates.
- The Toolbox can be used to predict the NBS options most suitable for a given subcatchment to reduce erosion, sedimentation, and woody debris. High-level sizing options for some NBS have been provided in the Toolbox (e.g., planting and debris traps) and the relative effectiveness given that size. However, the Toolbox should not be used to precisely locate, size or design NBS options within the catchment.
- Misclassification of land use in available datasets has resulted in incorrect prediction in the Toolbox. Efforts were taken to update the LCDB classification using aerial imagery both pre-and post-cyclone, but this was a manual process and not comprehensive, particularly for smaller areas. For example, if a section of existing riparian vegetation has been classified as

grassland, the model will suggest that section of land is feasible to implement a riparian margin NBS.

- Tolerance to the impact of storm effects takes into account buildings and bridges, but does not account for other infrastructure and assets, areas of cultural significance, or the temporal variation of forestry harvesting. See Section 4.2.2 for more detail.

5.4 Next steps

5.4.1 Next steps for GDC using the outputs/Toolbox

1 **Communication of Draft Toolbox and Workshop 3:** Following the delivery of the draft Toolbox and Workshop 3, engage in active dialogue with stakeholders and the wider community. It will be important to communicate the model's outputs and its intended uses and limitations.

2 **Feedback and Distribution:** Acknowledge and analyse the feedback received on the draft Toolbox and from Workshop 3. Post-feedback, GDC should initiate the distribution of the Toolbox both internally and externally. This will facilitate exploring potential NBS in the Waimatā catchment.

3 **Implementation of Toolbox Outputs:** The outcomes delivered by the Toolbox will help with the first steps of NBS planning in the Waimatā catchment. Users should start identifying the most effective NBS for distinct catchment areas.

4 **Expansion of NBS Options**: GDC to identify additional NBS options which can be incorporated into future model iterations. It's important to consider that some NBS may be specific to certain subcatchments. Therefore, an understanding of the terrain and specific catchment requirements is essential in this step.

5.4.2 Next steps – further versions of the Toolbox

Following GDC and stakeholder testing and trailing the Toolbox, improvements could be made.

The Toolbox’s effectiveness is currently limited by both the input data and scope of the project, so there are opportunities for improvement in several areas. Firstly, integrating a cost-analysis component could provide more comprehensive insight into the feasibility of proposed solutions and give stakeholders an indication of potential costs associated with each NBS. Secondly, the integration of co-benefits, or additional advantages that a solution could provide, could also be highlighted, which may provide more incentive to implement a given NBS. Thirdly, including opportunities for specialist inputs would increase the accuracy and effectiveness of the Toolbox, providing a more holistic approach.

NBS often excel at mitigating the impacts of smaller scale rainfall events, but their effectiveness could be amplified when strategically combined with hard infrastructure or protection measures. Consequently, the potential for hybrid solutions that blend both NBS, and traditional infrastructure approaches warrants further exploration to maximise the effectiveness of solutions.

It's essential to frame the Toolbox as a means to explore options to enhance resilience rather than design or completely negate potential hazards or damage. NBS are not a fix for all environmental risks, but they can contribute to building a more resilient community. This resilience relies on the capacity of an environment to recover more efficiently following significant rainfall events, thus minimising long-term impacts. This resilience-driven approach can fundamentally transform how we respond to and prepare for environmental challenges in the long run.

Additional detail and scale can be added to the tolerance mapping, especially by incorporating a more complete representation of the Te Ao Māori workstream and various sites of cultural significance. Working with mana whenua to gain empirical knowledge of the effects of NBS in the Waimatā and in Aotearoa is an important opportunity to incorporate indigenous knowledge towards catchment kaitiakitanga.

There is an opportunity to incorporate in the future phases of the project the work currently underway in Tairawhiti and/or other data from GDC's detailed hydrological and hydraulic modelling programmes, when this becomes available. Similarly, culvert daylighting can be included in the future scope of works when more detailed and accurate data becomes available.

Furthermore, geospatial datasets representing lifeline utilities, communication and energy networks, three waters infrastructure, rail and road, and other built infrastructure may provide key insight to the prioritisation and feasibility of NBS implementation.

6 Client feedback and response record

Following submission of the draft version of this report (Version 0.1), feedback and comments were received from GDC. These comments were addressed via email correspondence dated 8.07.2025, in which each point was responded to in detail. To ensure a clear record of the feedback and the associated responses, a copy of this correspondence has been included as Appendix B of this report. Appendix B serves to document the review process and confirm how client feedback has been considered and integrated where appropriate.

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8 Applicability

This report has been prepared for the exclusive use of our client Gisborne District Council and communities, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Tonkin & Taylor Ltd
Environmental and Engineering Consultants

Report prepared by:

....	....
Khendra Harvey Fluvial Geomorphologist	Daniel Le Roux GIS Analyst

Authorised for Tonkin & Taylor Ltd by:

....	....
Nathan McDougall Senior Data Scientist – Machine Learning	Josh Markham Project Director

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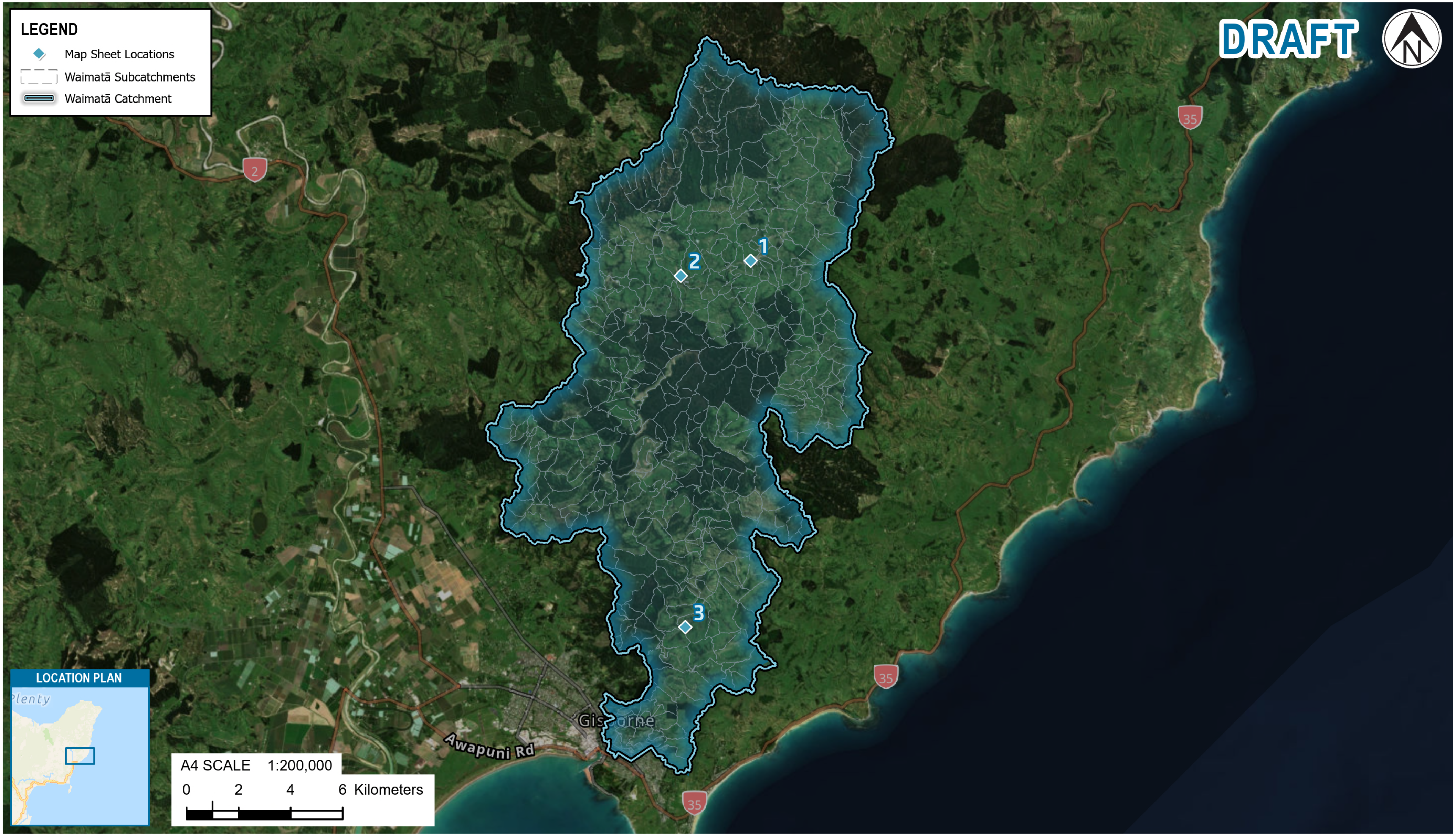
Appendix A GCD results



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PROJECT No.	1096486.0000	
DESIGNED	DSMI	MAR.25
DRAWN	DSMI	MAR.25
CHECKED		
DXLR	MAY.25	
APPROVED	DATE	

CLIENT **GISBORNE DISTRICT COUNCIL**
PROJECT **WAIMATĀ SPATIAL NATURE-BASED SOLUTION**
TITLE GCD RESULTS - INDEX
SCALE (A4) 1:200,000 FIG No. FIGURE 2-0 REV 0

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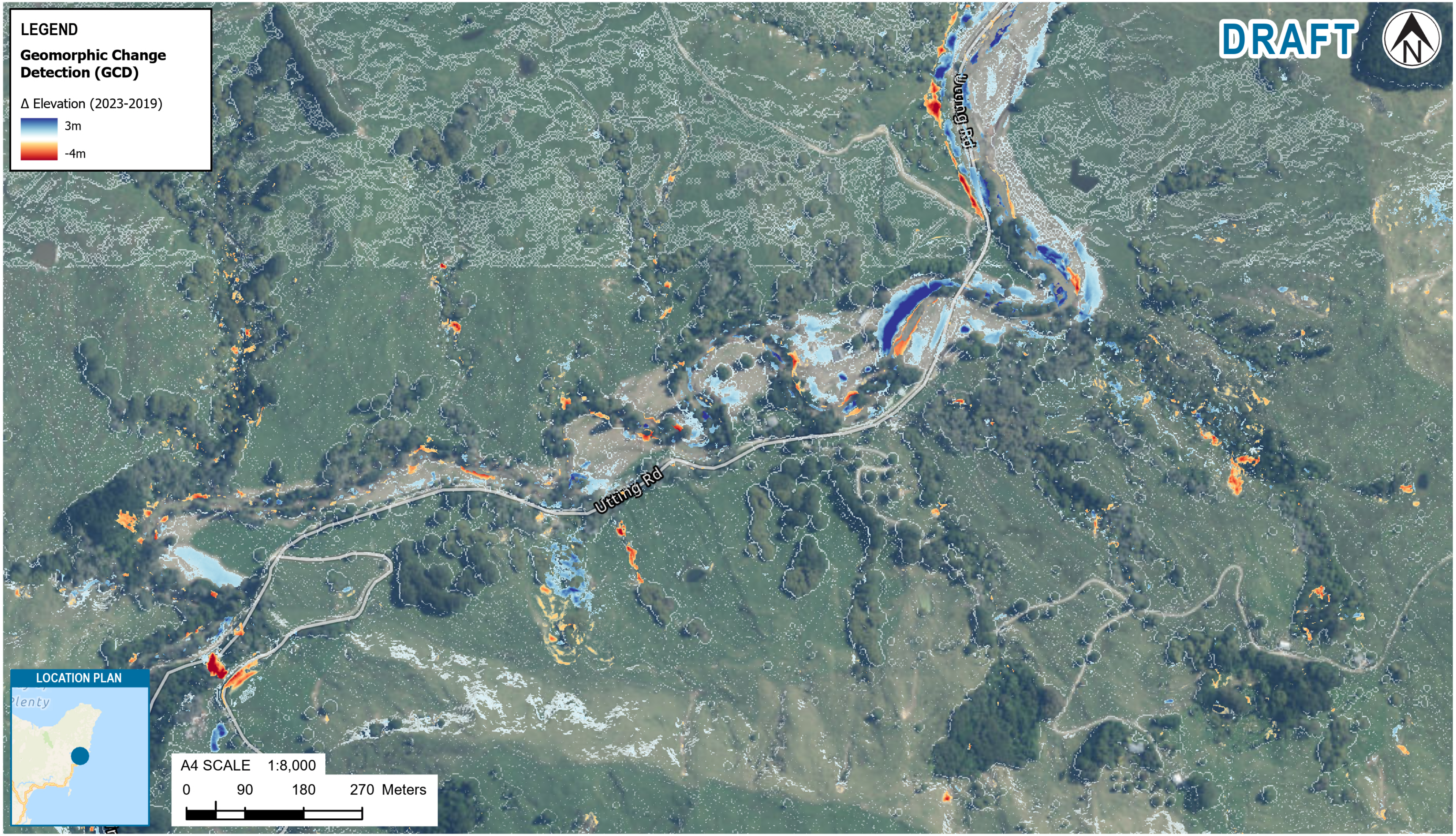

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PROJECT **WAIMATĀ SPATIAL NATURE-BASED SOLUTION**
TITLE GEOMORPHIC CHANGE DETECTION RESULTS (2023-2019)
SCALE (A4) 1:8,000 FIG No. FIGURE 2-1 REV 0

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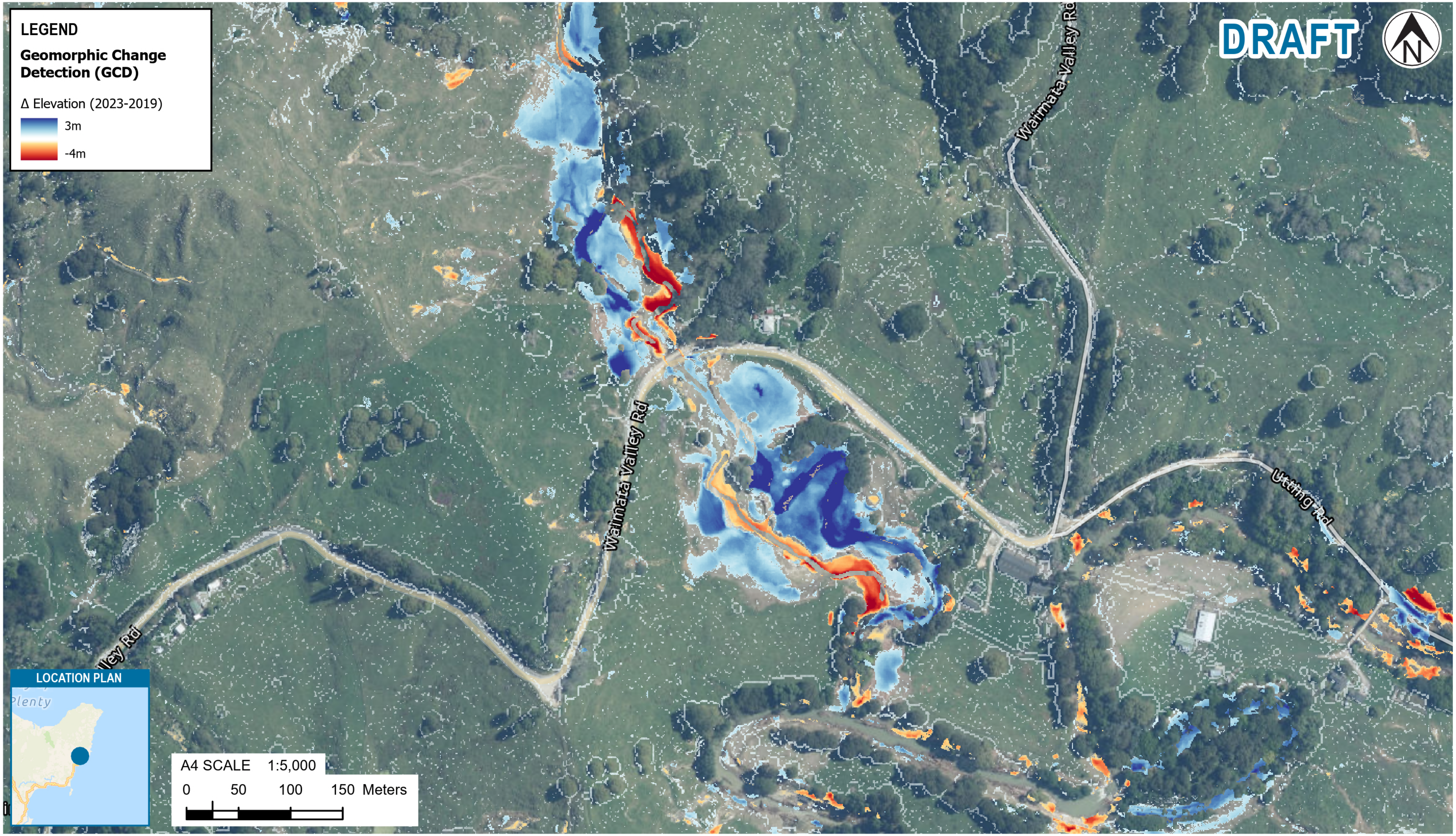

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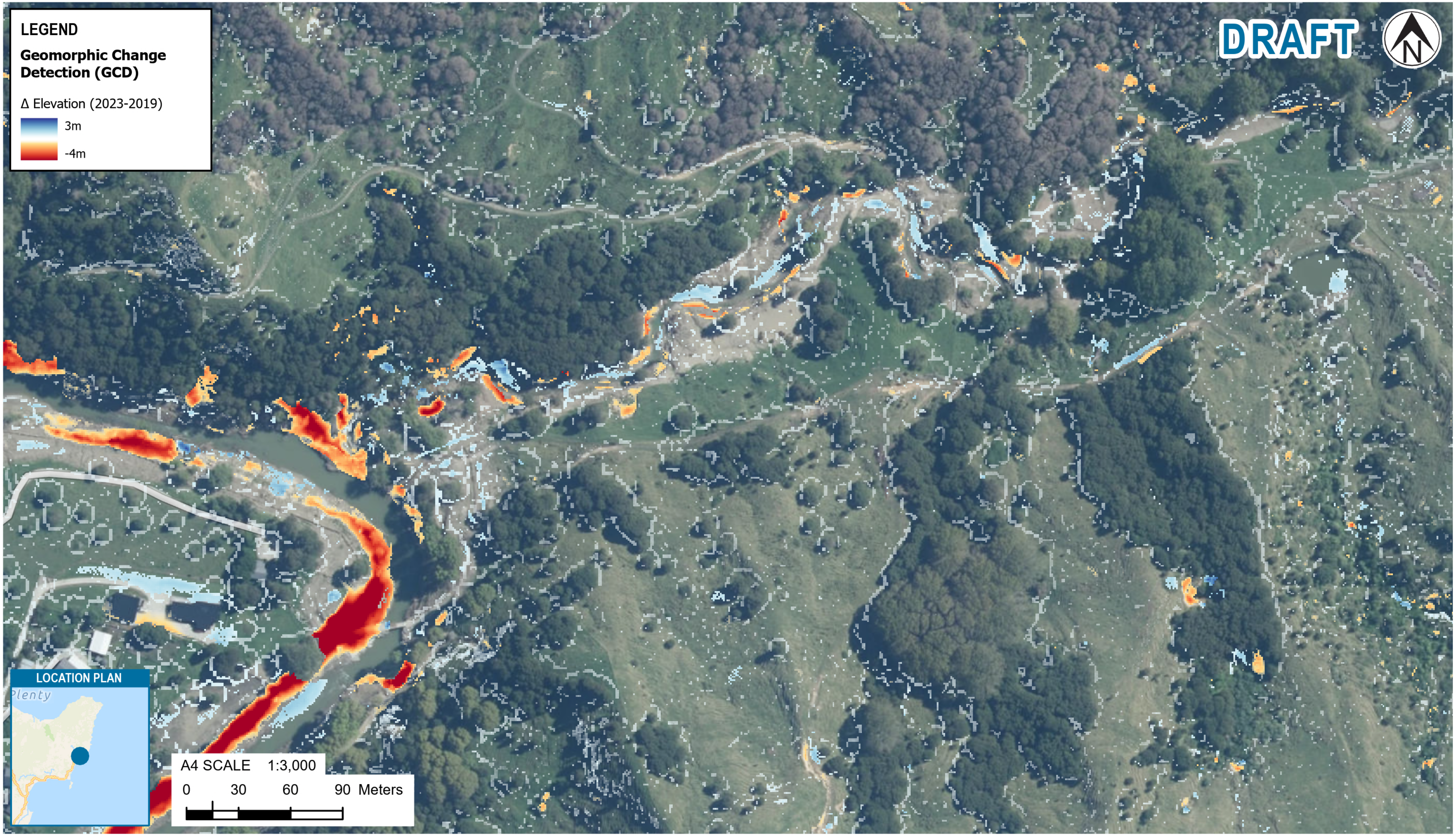

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CLIENT **GISBORNE DISTRICT COUNCIL**

PROJECT **WAIMATĀ SPATIAL NATURE-BASED SOLUTION**

TITLE GEOMORPHIC CHANGE DETECTION RESULTS (2023-2019)

SCALE (A4) 1:3,000 FIG No. FIGURE 2-3 REV 0

Appendix B Client feedback and response record

Wioletta Gilfoyle

From:	Wioletta Gilfoyle
Sent:	Tuesday, 8 July 2025 12:33 pm
To:	Sandy Butler; Nicki Davies
Cc:	Josh Markham
Subject:	Waimatā NBS Response to Draft Report comments + hydrology model scope
Attachments:	Waimatā NBS Toolbox User Guide_final.pdf

Dear Sandy and Nicki,

Hope you are well and keeping warm!

We've reviewed your comments to he Waimatā NBS Draft report. Please see below our responses and clarifications:

Item No.	Report Section	Comment	Author	T+T response	Amended in the report (Y / N)
1	Executive summary – Uses, constraints and limitations	We discussed this at Workshop 2 when Divesh (GDC hydrologist) highlighted this exact thing. Is this considered a limitation or more a statement? If its seen as a limitation then maybe the ability to select different event magnitude could be listed in Sec 5.4.2	Nicki	This is a statement. The Machine Learning models predict results based on the specific datasets given as inputs. The models we are using to analyse the Waimatā data are built on information that includes Cyclone Gabrielle, which is a major event. This means the models "learn" from that specific data to make predictions. The 'magnitude' isn't really a parameter that is able to be changed within the current data-driven architecture. Because these machine learning models only know how to predict outcomes based on the data they were trained with, it might not be reliable to use them to predict the results of events that are much smaller or larger in magnitude than what the training data shows. Adjusting or scaling the results for very different events may not be valid because the models weren't designed to handle changes outside the patterns in the input data. In summary, we delivered a model that was trained by the Cyclone Gabrielle catchment response because if NBS are effective in this event, they will inevitably be effective in mitigating impacts of smaller events. We understand this is of high importance to GDC due to the threat posed by climate change to increasing storm magnitudes in future. Therefore – this is not a limitation. However, it does need to be acknowledged that NBS are	N

				more likely to have a bigger impact in smaller events.	
2	As above	See Orlo's email - he is concerned about the tools needing to be reprogrammed and skillset required.	Nicki	Orlo has raised his questions in email before the User Guide document was shared with GDC and before our technical support (GID & data + analytics) session with GDC, guiding Orlo through the process and answering all questions. Based on the Orlo's feedback from the support session and the User Guide document, we are confident that the detail and clarity of the relevant sections in that document is sufficient to facilitate a GIS analyst to retrain the models. No reprogramming shall be required, but the collation of base data and running scripts naturally will still be needed.	N
3	4.2.2 Tolerance	As far as I was aware, we had provided road assets? Email from Mark Cockburn 17/02/2025	Nicki	The inclusion of road assets in the 'vulnerability' mapping in workshop 2 did not include or acknowledge road features specifically. Similarly for the extension of that workshop information into the final 'tolerance' mapping. Quick spatial analysis undertaken to test the results of including the total length of road in a subcatchment as an additional to bridges and buildings indicates insignificant change to the tolerance scores, which is highly correlated with the number of buildings.	N
4	4.3.3.1.1 Scale of modelling	What is the time and GIS data / information management capacity required to undertake this work in other catchments? Sounds like a lot of data points	Nicki	The number of data points may sound intimidating; however it is less overwhelming in a context of the size of the Waimatā catchment, which is 226 million m^2. The number of data points essentially represents the number of pixels in the Digital Elevation Model (DEM), not including other layers of data like slope, curvature, and others. Yes, working with such large datasets does take time, but this is completely normal when dealing with GIS data. Data of this size can be easily handled within the ArcGIS Pro Project file or through the scripts explained in the User Guide. These tools align with the established and tested methodology we've used for the Waimatā project.	N
5	Table 4.11	What were the percentages of vegetation cover used in the modelling assumptions based on? Is there an understating of how much sediment reduction occurs for each of these types of vegetation cover? Also what is the definition used	Nicki	The 5% coverage was based on literature (the Blashke et al. 2008). Productive land is defined by land use classes that are not already indigenous forest or established forest. The 5% vegetation cover for agroforestry is a starting point. It should be noted that what's actually more important in terms of this NBS is the specific placement of trees – it's a matter of the right tree in the right place – Raphael Spiekerman's modelling (2022) showed that, "Compared with a pasture-only baseline, a 34% reduction in sediment delivery can be achieved	Y

		for productive land capacity?		by increasing slope stability through spaced tree planting on 6.5% of the pastoral land." https://doi.org/10.1016/j.ecoleng.2022.106676, so the NBS ML model is really just a starting point for where to target this option in the catchment, it does not provide specific details on where that planting should occur, which is the role of land managers…	

Please let me know if, in addition to the last item, you would like any of the above information to be included in the report.

Please see the attached finalised User Guide document. The report will follow by end of this week.

On another topic, would you please share an update on the hydrological model scoping? I recall there were going to be discussions with GDC hydrologists to understand the needs etc?

Best regards,
Wioletta