CAN NATURE-BASED SOLUTIONS HOLD OUR SLOPES?

This paper has been peer reviewed

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ABSTRACT

In 2023, Cyclone Gabrielle and the Auckland Anniversary floods caused over 2,000 reported slips across Auckland's transport network, closing more than 130 roads. Climate instability is here, bringing with it heavier and more frequent rainfall which triggers landslides. Repairing or preventing these slips using traditional civil engineering methods alone is becoming increasingly unaffordable.

In response to the 2023 weather events, the Government and NZ Transport Agency Waka Kotahi (NZTA) established the Crown Resilience Programme (CRP). This includes a project to trial Nature-based solutions (NbS) to reduce the risks of slips on the Auckland motorway network.

This paper outlines the steps we took to determine what to trial and where, covering how we:

- Worked closely with NZTA and Auckland System Management (ASM)[1] stakeholders to define the problem and navigate challenges
- Formed a multidisciplinary project team of hydrogeologists, ecologists, geologists, soil scientists and engineers
- Conducted a rapid review of the literature to identify effective NbS methods and gather lessons learnt; the review revealed several NbS and natural experiments already in place in Auckland
- Developed a site selection methodology based on feasibility, risk, potential impact and cost
- Arrived at a preferred option comprising:
    - Two trials which combine soil nails to pin log fascining with planting that includes deeper-rooting native species
    - Research to locate and evaluate existing NbS/ natural experiments around the ASM network.

Ultimately, we need scalable, cost-effective ways to mitigate slope failures as well as a structured approach to determining where NbS can be used and how it performs. As climate change accelerates, slips will become more frequent and more expensive, unless we adapt our approach.

[1] Auckland System Management (ASM) is an alliance between HEB Construction, Fulton Hogan and NZTA to operate and maintain Auckland's motorway network. The ASM is a 9 year-contract that follows the Auckland Motorway Alliance (AMA) contract which ended on 30 June 2019.

INTRODUCTION

The severe weather events of 2023 highlighted how crucial it is to invest in early preventative works to protect our transport network (NZTA 2023).

In early 2023, Auckland experienced two of the most damaging weather events in its history: the Auckland Anniversary floods and Cyclone Gabrielle. Together these triggered over 2,000 reported slips across the region's transport network, closing more than 130 roads and causing widespread disruption. These events followed an unusually wet end to 2022 that resulted in usually elevated groundwater levels. When three intense, large rain events occurred in January and February slopes were easily saturated and destabilised. The result was tens of thousands of landslides across the region, many in places not previously identified as being at risk, revealing significant gaps in our understanding of slope vulnerability and highlighting an urgent need for new, proactive approaches to resilience (AC 2024).

In response to the widespread damage caused by these and other extreme weather events across New Zealand, the Government and NZ Transport Agency Waka Kotahi (NZTA) established the Crown Resilience Programme (CRP). The CRP has funded more than 200 projects nationwide, ranging from larger scale recovery and resilience-building works to smaller 'low cost, low risk' (LCLR) improvements, all aimed at strengthening the land transport network against future severe weather, improving resilience, and keeping communities connected (NZTA 2023). The Nature-based Solutions (NbS) Trial that is the subject of this paper is one of Auckland's CRP projects.

Nature-based Solutions (NbS) are increasingly being recognised- in New Zealand and overseas- as effective and sustainable methods to address environmental challenges. NbS are *approaches inspired and supported by Nature that offer cost-effective, resilient outcomes while delivering environmental, social, and economic benefits* (DOC 2020). The purpose of the Auckland NbS trial is to identify and trial practical, evidence-based interventions that use natural systems to stabilise slopes, reduce slip risks, and deliver more sustainable outcomes than traditional hard/ grey engineering. By testing combinations of planting and light-touch engineering, this project aims to demonstrate how NbS can be deployed across the network to enhance long-term resilience.

This paper presents an overview of the trial design, discusses key findings from the rapid review of the literature that informed its development, shares lessons learnt and seeks to answer the question: can Nature-based Solutions hold our slopes?

METHODOLOGY

The methodology comprised research, site selection, stakeholder and multidisciplinary design workshops, and field investigations. The project generally followed NZTA's Business Case Approach (NZTA n.d.), even though it was seeking solutions within the LCLR budget window i.e. under $2M. This included developing an investment logic map (see appendix) which defines the problems and sets out investment objectives for the trial. The NbS Trial Implementation Plan Report (Resolve, WWLA, Viridis, Initia & Manaaki Whenua, 2025) provides a detailed record of all aspects of the trial's development and design, and includes the rapid review of the literature which sought to answer the question: *what do we need to consider when selecting sites and designing 'low cost, low risk' approaches?*

A key task for the team was to select sites and appropriate NbS designs, drawing together learnings from the rapid review, input from stakeholders, findings from field investigations and considering how the trial could achieve the investment objectives set out in the ILM. An overview of the approach to site selection and trial design is shown in Figure 1.

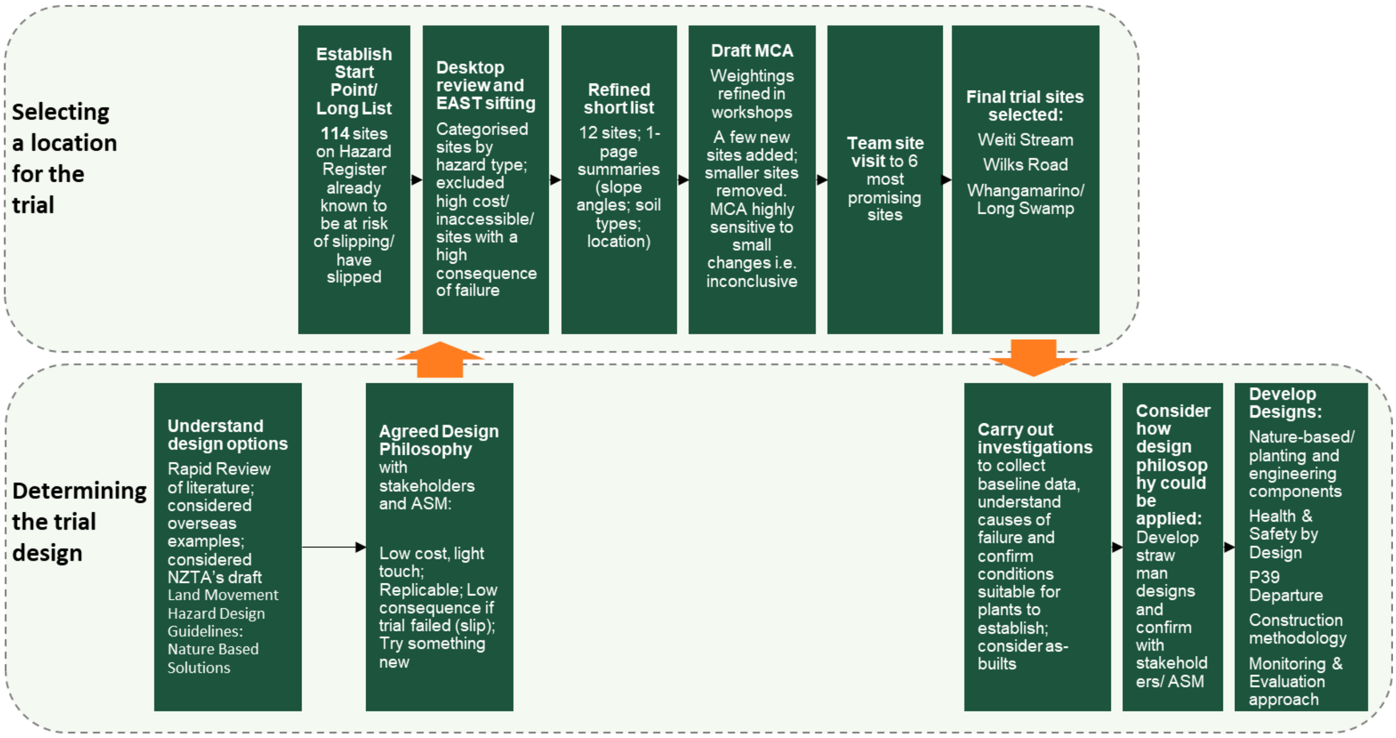

Figure 1 Overview of approach to site selection and trial design development

Through workshops with NZTA and ASM, and considering the findings of the literature review, the team confirmed that the trial should test low cost, light touch designs that have the potential to be scaled across the network (see example in Figure 2); it should also seek to test something new, while prioritising sites with access arrangements that avoided costly lane closures or night works and either aligning with NZTA standards (e.g. (including Safety Audits, P39 – Standard Specification for Highway Landscape Treatments, and the Bridge Manual)) or seek departures where appropriate. The team had been tasked with applying the draft Land Movement Hazard Design Guidelines: Nature Based Solutions (NZTA 2024); the draft guide stated that NZTA *has a preference for hybrid solutions* and hence that is what the team set out to trial. Mickovski et al (2024) explain hybrid solutions as follows: *NbS for slope protection should combine structural with living elements. The structural elements will reinforce the soil and provide stability in the early stages after NbS deployment. The living elements mostly comprise vegetation, which will take over the reinforcing role (Tardio and Mickovski, 2015) once established whilst blending the intervention into the landscape and the fostering ecological succession of the site.*

After the design philosophy had been confirmed with stakeholders, the team shortlisted and selected trial sites, combining desktop analysis, field investigations, and team site visits with input from NZTA and ASM stakeholders. Through a series of design workshops, the hybrid design philosophy was tested and refined, integrating measures such as drainage, soil anchoring, and log or sleeper benching with native planting. The output of this work was detailed trial designs, cost estimates, planting plans, vegetation management plans and construction methodologies for Wilks Road and Weiti Stream, as well as a design direction for Whangamarino / Long Swamp.

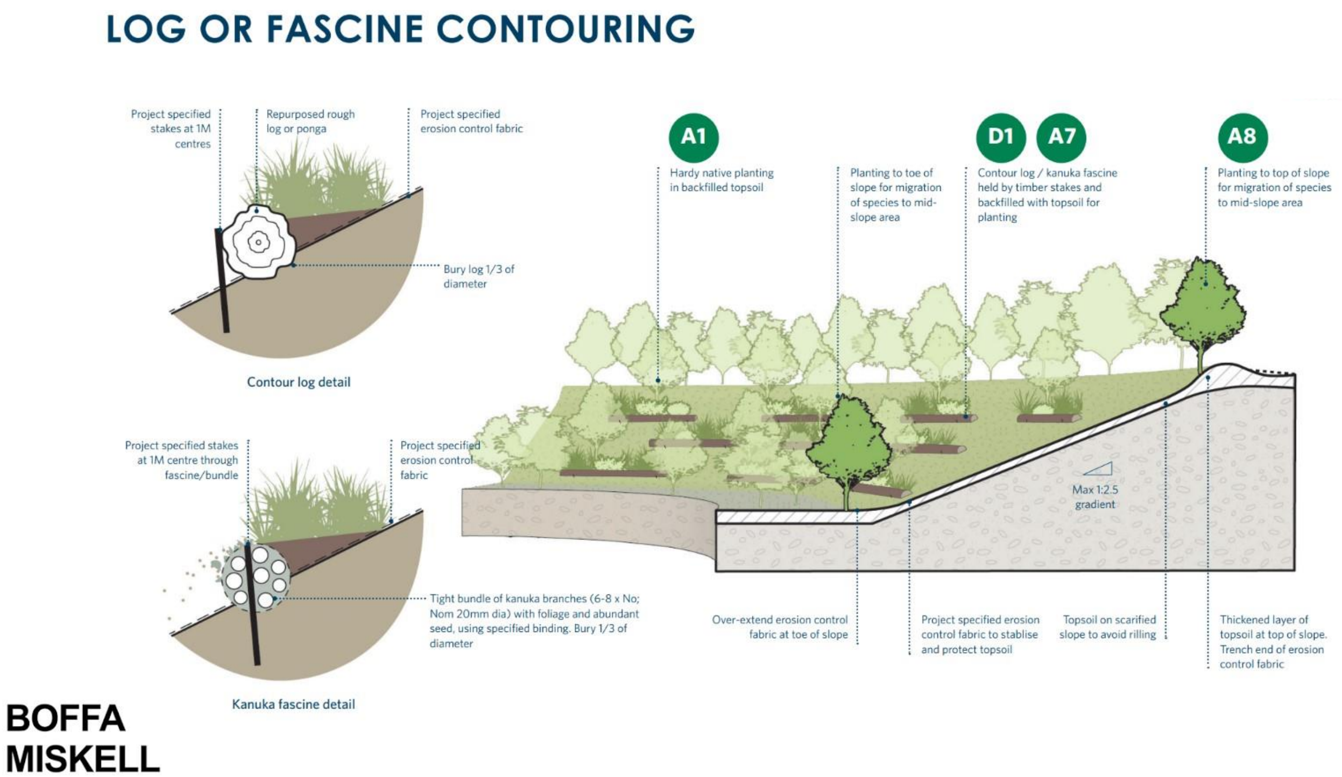

Figure 2 This 'Matrix Design' from the early NZTA scoping work on Nature Based Solutions for Land Movement Hazard Design Guidelines (NZTA 2024), which was the preferred approach in the workshop: it's low cost and scalable.

TRIAL SITES AND DESIGNS

Figure 3 Photos of trial sites, from left to right: Weiti Stream, Wilks Road, Whangamarino/ Long Swamp

WEITI STREAM (SH1, NORTHBOUND) was chosen as it offers a shallow slip with good access. The site is adjacent to a Significant Ecological Area (SEA), offering the potential for an NbS to connect with the adjoining native bush block, supporting nature regeneration. Investigations found the failure mechanism to be an embankment slip caused by water building up between layers of engineered fill. Hand augers found approximately ½ m of topsoil across most of the site (some having slipped) which would be sufficient for plants to establish.

WILKS ROAD (SH1, SOUTHBOUND) was selected because it represents a typical motorway cutting: a shallow slip in sensitive clays. The site offers easy access, a fairly uniform slope profile, and enough space for an adjacent 'planting only' control area. ASM had received several calls from the public about the slip, so there was an appetite to treat it. Investigations identified the cause of failure as a shallow movement within the clay cutting, driven by elevated groundwater pressures. Reducing these pressures through drainage would help to stabilise the slope. The topsoil layer varies from 0.3 to 0.5 m, with mottling to around 0.7 m, which is sufficient to support plant establishment.

WHANGAMARINO / LONG SWAMP (SH1, SOUTHBOUND) is a large slip where a traditional reinforced embankment was designed but later deemed prohibitively expensive. The site was added to the trial to explore NbS as a lower cost alternative for deeper slips. Located on the east side of SH1 near Pōkeno, the slip extends into farmland acquired and re-fenced by NZTA. The slope is considered to be relatively stable, having reached its natural angle of repose. Implementation is being managed as part of the Whangamarino / Long Swamp project.

DESIGN FOR CONSTRUCTION: WILKS ROAD SITE

The design combines drainage, slope stabilisation, and staged planting to provide interim engineered stability while vegetation establishes.

- Ground-anchored logs and benching: Staggered logs or sleepers will be pinned in place with ground anchors, with the first row set back at least 9m from the carriageway. The staggered layout avoids creating overland flow paths, and logs will be partially buried to minimise vehicle damage risk. Anchors prevent downslope movement and provide temporary support while plants establish. Logs will be backfilled with topsoil and mulch to create level planting benches (Figure 4).
- Counterfort drainage: Counterfort drains will be installed at 12m centres, running upslope at 90 degrees to the motorway and discharging into a bioswale at the toe of the cutting.
- Control area: An adjacent "planting-only" control block will allow direct comparison with the hybrid section.
- Planting design: Approximately 2,470 m² will be planted for erosion control and bank stabilisation (Figure 5) using a T cut planting method (from forestry):
  - Stage 1 (Year 1): Establish a nurse crop dominated by mānuka and kānuka to provide rapid canopy cover, suppress kikuyu, and stabilise the slope. Taller plant grades will be used to speed establishment and avoid the need for grass spraying, drawing on successful iwi pasture trials in the Waikato.
  - Stage 2 (Year 2): Introduce enrichment species at wider spacings (up to 7 m), focusing on deeper-rooting species identified in Stage 1.

This two-stage approach enables quick canopy closure while protecting slower-growing, deep-rooting species from exposure and competition.

- Bioswale and landscape integration: The existing swale will be reshaped into a 2 m-wide bioswale (approx. 380 m²) planted with indigenous species to improve stormwater filtration. Extending planting beyond the soil- anchored area:
  - Trials a "plants-only" section alongside the hybrid design
  - Softens the landscape appearance
  - Eliminates maintenance of a remnant grass strip; and
  - Improves safe site access by directing staff to a barrier-protected parking area at the southern end.

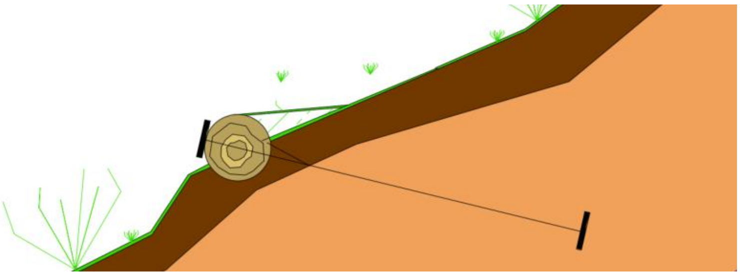

Figure 4 Cross section showing ground anchored logs/ sleepers and benching behind (WWLA 2025)

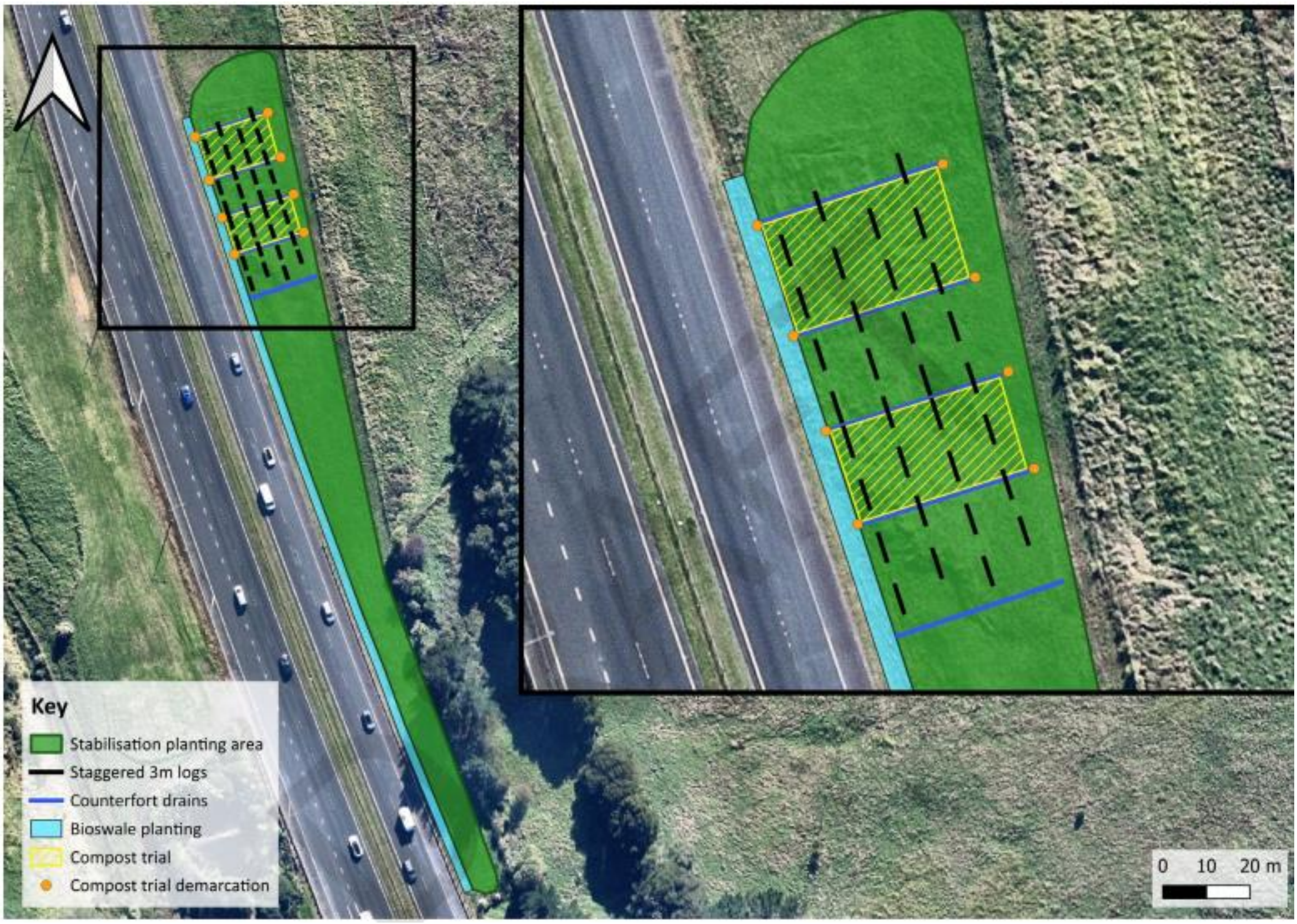

Figure 5 Planting Plan for Wilks Road slope, French drains and swale planting (Viridis 2025)

Design for Construction: Weiti Stream

Weiti Stream trials a hybrid design similar to Wilks Road, combining staggered, ground-anchored logs/ sleepers, improved drainage, and planting (Figure 6). Approximately 995 m² will be planted using the T-cut method. The design reinstates and extends nearly 100 m of bioswale at the top of the slope, connecting it to existing apron drains to intercept surface runoff from the motorway and dewater the slope to some extent. Logs and sleepers follow the natural contour and will be backfilled with topsoil and mulch to form benches that reduce erosion and support plant establishment. All elements are set back from the culvert and stream to avoid blockages during high-flow events.

Species identified during Stage 1 as having comparatively deeper or more extensive root systems- (toetoe (*Austroderia spp.*), tārata (lemonwood, *Pittosporum eugenioides*), and tī kōuka (cabbage tree, *Cordyline australis*)) *Phillips et al.* (2023)- have been included in the planting palette, and the trial area extends to the adjoining Significant Ecological Area (SEA) to enhance ecological connectivity and soften the northern landscape edge. A perimeter row of harekeke (flax, *Phormium tenax*) provides a buffer from the motorway and protects young plants, particularly toetoe, from spray drift. In addition to providing stability, the planting will extend habitat and improve runoff filtration of nutrients, sediment, and other contaminants.

A monitoring and evaluation framework for the trial sites has been developed; this focuses on both geotechnical and ecological performance, supported by baseline data collected during site investigations.

LOCATING AND EVALUATING EXISTING NATURE-BASED SOLUTIONS AND NATURAL EXPERIMENTS AROUND THE ASM NETWORK

In addition to selecting and designing the new trial sites, the NbS Trial project will include a task to locate and evaluate existing NbS and natural experiments around the ASM network, potentially allowing the trial to realise its investment objectives (see appendix) years earlier.

Figure 6 Planting Plan for Weiti Stream (Viridis 2025)

NZTA plans to construct/ plant the trial sites before winter 2026 and the CRP NbS Trial budget will support monitoring and evaluation, and vegetation management for the following three years, after which the asset will be handed to ASM.

DISCUSSION

This trial contributes to a growing national focus on NbS. At the time of writing, NZTA is progressing several initiatives that strengthen national support for NbS, including an Introductory Guide to Nature-based Solutions, updates to NZTA Highway Landscape Guidelines, P39 *Standard Specification for Highway Landscape Treatments*, and a project investigating how native planting reinforces slopes.

The discussion that follows reflects a set of interrelated themes that emerged through the trial, relating to the complexity of multidisciplinary delivery, soil conditions and compaction, species selection, definition and tolerance of risk, groundwater management, and the practical limits imposed by slope geometry and root penetration. Together, these factors shape where and how NbS can be successfully applied within transport corridors, and inform decisions about their suitability as low-cost, low-risk interventions.

Given the complexities of linear transport corridors, NbS is inherently multi-disciplinary (IoD 2021, Mickovski et al. 2024), this makes the process of their design, implementation and management more complex when compared to traditional 'hard' engineering single-solution works, particularly for hybrid designs. Further, unlike hard engineering, which usually offers a 'once and done' approach, NbS may have multiple stages of implementation and establishment e.g. initial hard/ grey engineering treatment to stabilise a slope while waiting for plants to establish. Then once plants are established, reinforcement grows as the root network matures, although this can happen over time (e.g. grasses> shrubs> trees). The whole process requires more active monitoring to check the treatment is performing as it should be, that plants are alive and thriving, trees may need to be trimmed, and weeds need to be controlled. However, when viewed through a whole-of-life and value-for-money lens, NbS and hybrid treatments can offer more sustainable and cost-effective outcomes than traditional hard/ grey engineering. Critically, when considering corridor or region-wide approaches to resilience[2], investment decisions should weigh the potential to achieve broader resilience benefits and other benefits (aesthetic, biodiversity) through the widespread rollout of NbS on lower risk, less steep slopes against the higher cost of treating a smaller number of high-risk sites using conventional methods that do not deliver broader benefits.

Our project team was multi-disciplinary, as was our stakeholder group and this did make management of the project and design more complex, challenging and interesting. At times, it felt like different experts were working in parallel rather than together towards one solution, this will improve as teams gain experience of developing hybrid NbS designs.

Our experience confirmed several issues highlighted in the literature particularly the influence of soil compaction and species selection on success. Effective NbS design requires understanding the cause of failure and consequences of future movement, as well as assessing whether soil conditions are or could be made suitable for plants to establish and thrive. Compacted ground is deliberately created to reduce water infiltration to engineered slopes but can prevent or limit root penetration, hence site visits and geotechnical investigations e.g. hand augers to provide insights into topsoil depth, potential rooting depths, compaction and soil structure, are necessary to inform designs and determine whether NbS is a viable option 'here'. The challenges of compacted ground within the road corridor are different from those in agricultural settings. In the transport corridor, compaction typically extends deep into the subsoil layers and is intentionally achieved through engineered cut and fill, sometimes certified to meet design standards for stability and pavement performance. Further, it is often applied evenly over large areas and results in sharp boundaries with (looser) applied topsoil. In contrast, agricultural compaction is usually limited to a shallow surface layer or shallow pan. While this engineered compaction provides structural stability, it also restricts root penetration in combination with sharp boundaries between upper layers.

Species selection is also critical. Evidence from *Phillips et al.* (2023) and the NZ Geotechnical Society's *Slope Stability Guidance* (2024) explains that while there is information available about exotic species such as willows and poplars, empirical data on the performance of native species to stabilise slopes remains limited. Among those studied, toetoe (*Austroderia spp.*), tārata (lemonwood, *Pittosporum eugenioides*), and tī kōuka (cabbage tree, *Cordyline australis*) show comparatively deeper or more extensive root systems and strong potential for long-term slope reinforcement. The NZGS guidance recommends mixed planting, noting that combining species with varying rooting depths/types provides more resilient slope performance than reliance on a single species. Further, planting density, soil depth and fertility influence the time for plant roots to occupy soils and stabilise slopes – no native plants can match poplars in speed of root growth.

Adopting NbS requires a different tolerance for risk. During establishment, slopes may exhibit temporary instability until plants can get their roots down. For this reason, the Wilks and Weiti trials adopted hybrid designs to provide short term stability while the vegetation establishes. In comparison to hard/ grey engineering, NbS is more vulnerable to environmental hazards such as high rainfall, drought or wildfire, but unlike hard/ grey engineering, it can offer the benefit of

[2] For example, when using tools such as the More Than Water (MTW) assessment tool which was developed for evaluating the benefits and costs of Water Sensitive Urban Design (WSUD) projects (Moores et al 2019)

regenerating Nature, capturing carbon, reducing the urban heat island effect, restoring natural water cycles and beautification with some biodiversity benefits also possible. While NbS/ hybrid treatments for slopes cannot provide the stability of, say, a large retaining structure, they do have the potential to make slopes less prone to failure or more resilient to high rainfall events often at a lower whole-of-life cost.

Groundwater management is a key determinant of success. Studies (Gariano & Olausen 2016; González et al. 2023; USGS 2008; US Army Corps of Engineers EM 1110-2-1902) confirm that rainfall-induced increases in pore water pressure are the dominant trigger of landslides, and that drainage is one of the most reliable ways to improve slope stability. Both the Wilks and Weiti trial sites therefore included drainage and bioswales to reduce excess water. The mixed native planting palette also contributes to dewatering in the medium term and offers an advantage over exotic species because plants will be in leaf year-round, hence at least some plants in the mix will be intercepting rainfall and using water in winter which is Auckland’s wettest season.

NbS do have practical limitations. International guidance (USDA NRCS 2007) notes that grasses and groundcovers perform up to gradients of 3:1 and shrubs or small trees to 2:1; slopes steeper than this may not be suitable for NbS without hard/ engineered structural support that improves the slope’s factor of safety (i.e. a hybrid design). Similarly, if the slip plane lies deeper than 0.5 to 1m, many plant roots may never reach the failure zone. It can take several years to several decades for meaningful root reinforcement to develop, and this will be slower if the soil is poor (fill or compacted material) or plant spacings are wide.

Based on these insights, NbS are most suitable where:

- There is adequate topsoil and subsoil depth and (potential) quality for plants to establish and get their roots down
- Hybrid designs can provide stability while plants establish and landscape design can complement the slope system in providing broader benefits (e.g. aesthetics, buffering existing habitat)
- Network operations teams are open to approaches that carry some uncertainty; for our trial this was on sites where the slopes were considered to be low-risk and failure was not expected to cause disruption to the state highway. Underslips are generally more costly to repair than overslips, so the risk appetite may be greater than for overslips that can be cleared relatively quickly
- Site access is safe and low cost to support vegetation management, particularly in the first few years of establishment when plants require releasing from weed competition; and
- The cost of temporary traffic management isn’t prohibitively expensive (for investigations, construction/ planting, and monitoring/ maintenance).

To support broader rollout, these approaches could help to identify suitable sites:

1. Refining the ASM Hazard Register and applying the selection criteria and multi-criteria analysis developed in this trial; and
2. Applying LiDAR tools to predict landslide susceptibility could help to prioritise slopes with conditions favourable for NbS treatments around Auckland’s state highway network; Auckland Council and Auckland Transport have carried out research or developed AI tools and applied these in the Auckland region (McLelland & Roberts 2025; Bebelman, C. 2025).

Beyond technical challenges, stakeholders highlighted that funding models or criteria can affect feasibility. Current funding models rarely support preventive maintenance, revising these could enable wider use of NbS for proactive resilience works.

Taken together, these findings highlight that NbS are not a direct substitute for traditional hard/ grey engineering, but a complementary approach whose effectiveness depends on careful site selection, an understanding of failure mechanisms, and an acceptance of managed uncertainty during establishment. Where soil conditions, slope geometry, access, and risk context are favourable, hybrid NbS designs can provide meaningful improvements in slope resilience while delivering wider environmental and landscape benefits.

Importantly, the trial reinforces that successful application of NbS requires early multidisciplinary collaboration, alignment with operational and safety requirements, and a whole-of-life perspective that considers value for money across a corridor or network. These insights provide a practical foundation for refining guidance, improving decision-making, and supporting broader, evidence-based uptake of NbS across New Zealand's land transport system.

CONCLUSIONS AND RECOMMENDATIONS

This Nature-Based Solutions Trial demonstrates a practical approach to managing slope instability on New Zealand's transport network. By combining drainage and soil anchoring with native planting, the trial is testing whether hybrid NbS designs can deliver cost-effective and resilient outcomes on state highway side slopes and cuttings.

Key lessons learnt include:

- Selecting suitable sites proved more complex than expected. Each slip presents unique conditions, and underslips can be costlier to address than overslips, especially given the high cost of temporary traffic management
- The success of NbS depends on understanding failure mechanisms, managing groundwater effectively, and confirming that soil conditions will allow- or can be ameliorated to allow- vegetation to establish and reinforce the slope
- Hybrid approaches, which combine light-touch engineering with native planting, provide a balanced way to manage short-term stability while allowing long-term root reinforcement to develop
- Designs must align with NZTA and national standards (e.g. Safety Audits, P39, Bridge Manual) or seek appropriate departures
- Multi-disciplinary collaboration, including early involvement of maintenance teams, landscape architects and iwi partners, was essential for developing practical and accepted solutions
- The evidence base for NbS is still emerging; staying connected to national and international guidance and case studies will be vital as the local evidence base grows.

The CRP NbS trial contributes directly to New Zealand's developing NbS evidence base and will inform updates to NZTA's NbS guidelines. Future stages should focus on:

- Monitoring and evaluating slope performance over time, and how the landscape assets develop over time with the engineered elements and under ongoing maintenance
- Developing design guidance and cost benchmarks for broader application; and
- Aligning NbS performance metrics with NZTA's resilience and sustainability goals.

In conclusion, Nature-Based Solutions *can* hold some of our slopes, and, in many places, they already do. Many of the services highway landscapes provide have not been captured with this lens. Success depends on understanding the causes of failure, managing water effectively, and applying just enough engineering to give Nature time to take over the stabilising role. When these principles are followed, NbS offer a realistic, affordable, and sustainable path to making New Zealand's transport network more resilient to climate instability and the more frequent severe weather events that lie ahead.

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ACKNOWLEDGEMENTS

The authors wish to acknowledge those without whom this project would not have happened:

NZTA employees and stakeholders that made this project possible including Rosy Kurera, Sam Bourne, Emma Golightly, Peter Hartley, Dan Burgess, Richard Topham, Dante Legaspi, Sigfrid Dupre, Rajika.

Auckland System Management stakeholders for their support of the project or assistance with site visits: Peter Mitchell, David Withers, Va Mauala, Michaela Williams, Vi Hausia, Lawrence Butcher and Phil McLarin.

The Auckland Northern State Highway Iwi Central/West Integration Group (IIG).

The NbS Trial Design Consultant Team which was led by Resolve (the authors) and comprised: Resolve- Darren Edwards, Keith Swedhin, Nik Vorster, Debbie Keane, Tim Crow and Karen Fehl; Williamson Water and Land Advisory- Jaide Derbyshire, Jack Bretowich, Chris Simpson, Jon Williamson; Viridis: Brittany Pearce, Mark Delany; Initia: Matt Wansbone; and Bioeconomy Science Institute - Manaaki Whenua - Landcare Research Group: Dr Robyn Simcock.

AUTHOR CONTRIBUTION STATEMENT

Louise Baker was the Lead Author of this paper; she was also the Project Manager and Technical Lead for the NbS Trial Implementation Plan project. Stuart McDougall was the Trial Design Manager, with a focus on the engineering component, economics and business case aspects; Stuart contributed towards the discussion and designs included in this paper and developed the investment logic map. The methodology section of the paper has drawn heavily from reports and designs developed by the Resolve/WWLA/Viridis/Initia/Manaaki Whenua Trial Implementation Plan team.

KEYWORDS

Nature-based Solutions (NbS); slope stability; hybrid design; resilience; drainage; climate adaptation; NZ Transport Agency Waka Kotahi (NZTA)

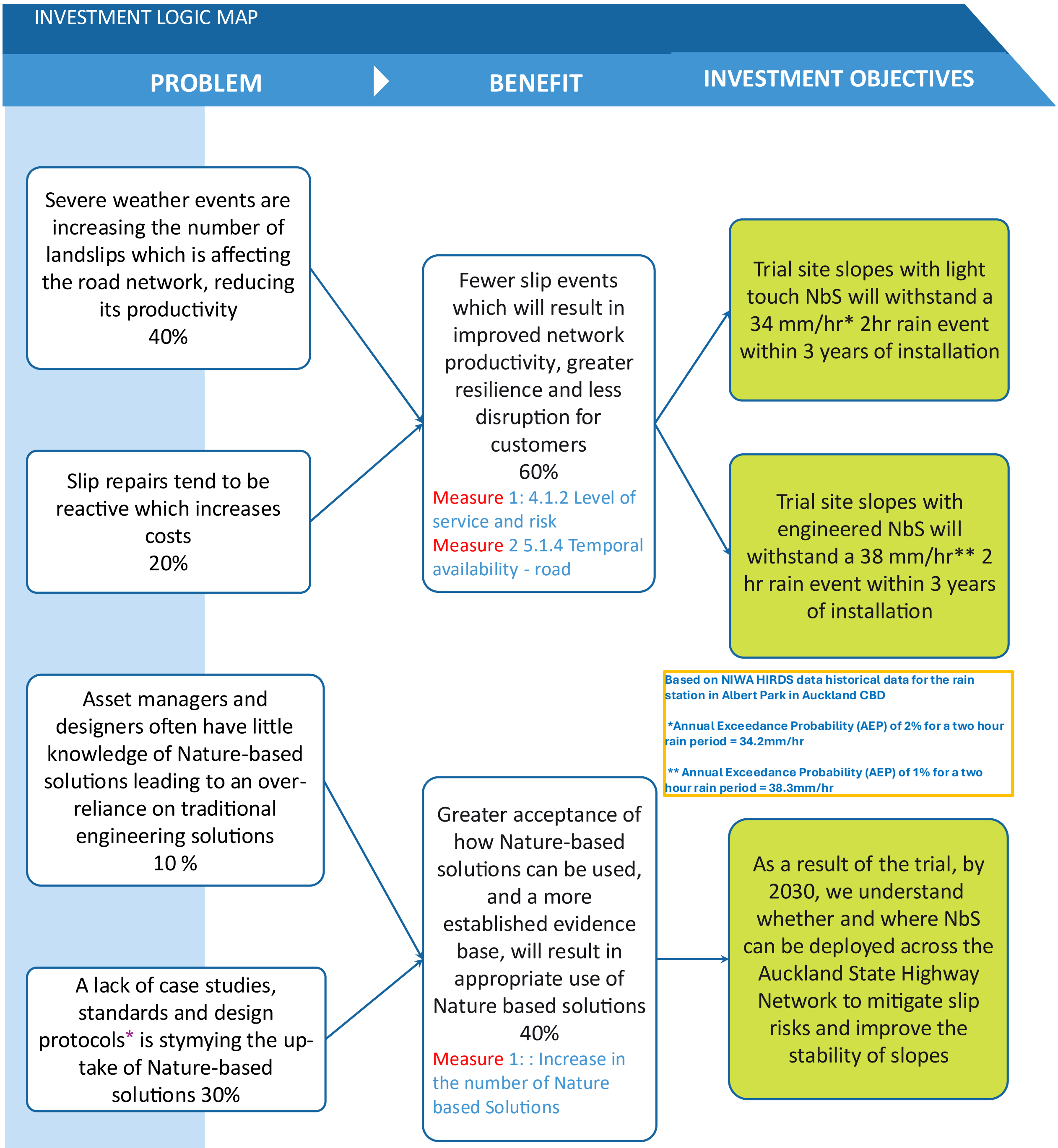
APPENDIX: INVESTMENT LOGIC MAP

Nature Based Solutions

Auckland Motorway Network NbS Trial

FINAL

WAKA KOTAHI NZ TRANSPORT AGENCY



* NZTA'S Nature-Based Solutions (for landslides) design guidelines are under development with a draft for consultation expected l ater in 2025

Business Problem Owner: Rosy Kurera
Facilitator: Stuart McDougall
Accredited Facilitator: No

Version no:	3 (final)
Initial Workshop:	10 December 2024
Last modified by:	Louise Baker 21 August 2025
Template version:	5.0