Aratu Forests Limited Submission on the Ministerial Inquiry into Land Use

Date: 4 April 2023

Introduction

1. The recent catastrophic events in Tairāwhiti and Wairoa highlight the need to swiftly address the issue of mobilised woody debris and sediment, and the significant impact it is having on the community. Aratu Forests Limited ("**Aratu**") is committed to taking action to contribute to resolving this issue. Some actions can be initiated rapidly and have almost immediate effect. Others, due to their nature, fit into the medium, and longer-term time frame for implementation and for the effects to be recognised.

Aratu

2. Aratu (formerly Hikurangi Forest Farms) is a large owner and manager of plantation forestry in Tairāwhiti and Wairoa. Aratu currently manages around 35,000 hectares of freehold land and land linked to joint ventures with local landowners including iwi. Of this total area, approximately 12% (4,200 hectares) constitutes reserves of ecological significance, and around 70% (24,700 hectares) is classified as productive forest estate and actively managed for timber production. The majority is Radiata pine, with smaller areas of various Eucalyptus species and Douglas fir also present. The remaining area includes roads, landings, unplantable areas and areas used for public utilities.

3. Aratu is governed by a Board, including two independent directors. The Gisborne office employs 28 staff, and around 250 contract workers are engaged working in the forests on any one day. In the last 12 months, Aratu has represented 24% of the log volume shipped across Eastland Port. Annually, Aratu also sells approximately 10% of its 700,000 tonnes of sawlog harvest to local sawmills, and around 15,000 tonnes of residues to Renalls' chipping plant at Matawhero. Aratu is both Forest Stewardship Council ("**FSC**") and Programme for the Endorsement of Forest Certification ("**PEFC**") certified, which means Aratu's performance on Environmental, Social and Governance facets of its business is independently audited annually.

4. A number of initiatives have been implemented by Aratu since purchasing Hikurangi Forest Farms in 2019 to reduce the risk of woody debris mobilising. These include an active program of building roads and harvest landings to a civil construction standard, and forming a joint venture with eLandNZ[1] that, since 2021, has planted 100 hectares of harvested land which Aratu has decided to retire to indigenous plant species (approximately 5% of Aratu's annual harvested area). Aratu believes that it can diversify its business by introducing new projects that are focused on societal benefits, including biodiversity enhancement and indigenous species restoration.

5. Our submission sets out recommendations that will help forestry businesses significantly reduce negative impacts on the communities they operate in. Forestry currently forms a cornerstone of Tairāwhiti's economy through direct employment, and wider economic benefits. As a part of the community, Aratu must regain the trust and confidence of the people of the regions it operates in, and we hope our submission demonstrates our commitment to doing so.

Executive Summary

6. Given the unique environment of Tairāwhiti, and its history, addressed at **Appendix 1 and Appendix 2**, it is imperative that careful, appropriate management of land identified as highly erodible is conducted. This will need to include afforestation, using a range of indigenous and

[1] eLandNZ – www.eLandNZ.com a company specialising in transitioning land use to sustainable uses primarily by monetising environmental benefits of native tree planting.

exotic species as specific situations require. For sufficient change to occur, the forestry industry and both central and local government will need to work in tandem.

7. The plantations in the region were developed using best intentions and science of the day to provide enhanced economic and environmental benefits to Tairāwhiti, including erosion reduction. As these plantations have matured, and been harvested, unforeseen negative consequences, in particular the mobilisation of woody debris and silt, have been encountered resulting in negative impacts to downstream communities.

8. With the benefit of hindsight, it is clear that some areas should not have been established in commercial exotic forestry. Consequently, some areas that were planted should not be harvested and some areas that have been harvested should not be re-established in commercial exotic forestry.

9. Solutions to prevent the mobilisation of woody debris and silt from forestry estates need to be carefully considered and implemented to minimise negative future consequences. In particular, Aratu recommends the following approaches to ensure improved management of the risk of woody debris mobilisation; noting, however, that it will be important to take regional differences into account before implementing any such measures on a nationwide basis:

   (a) **Commission an independent science-based approach to catchment limits and coupe harvesting limits:** Develop catchment or sub-catchment limits (which restrict the overall amount logged within a catchment in a defined period), and coupe harvest limits and green up rules (which limit the extent of clearfelling in adjoining sections) based on scientific, third-party research.

   (b) **Apply best practice pre-harvest planning**: Support forestry companies to further develop their pre-harvest planning approaches. In particular, the creation of a standard operating procedure, detailing a robust harvesting risk assessment process that addresses onsite and off-site effects, and preventative and recovery controls. Te Uru Rākau could assist in providing support to companies and regulators in the development of techniques, standards and compliance processes.

   (c) **Further develop regional forestry infrastructure standards**: Set standards for in-forest roading, waterway crossings, and landings,[2] in addition to the standards contained in the Forestry Owners' Association Road Engineering Manual, to help ensure that they remain stable during extreme weather events, given the Tairāwhiti region's erosion issues. Also, expand on erosion and sediment control structure methods to help lessen risks associated with landslides commonly triggered through water control outlets, such as cutouts and culverts. Te Uru Rākau could assist in providing support to companies and regulators in the development of techniques, standards and compliance processes.

   (d) **Improve in-forest management to reduce woody debris mobilisation risk:** Introduce both short-term and long-term measures to deal with woody debris mobilisation, including:

      (i) *Address large woody debris on vulnerable areas*: Support forestry companies to reduce large woody debris left on landslide vulnerable areas to the extent that it is operationally possible.

2 The area of land where logs are accumulated, processed, and loaded for removal.

(ii) *Increase residue utilisation*: Encourage the development of sustainable economically viable industries that consume woody residues from all sources.

(iii) *Make it easier for companies to install and manage a range of debris retention mechanisms*: Develop resource consent processes that allow for engineered (e.g. debris nets) and non-engineered (e.g vegetative barriers and debris "run off"[3] areas) retention mechanisms to be implemented via a clear and cost effective approval process.

(iv) *Ensure adopted silviculture regimes, including establishment practices, do not increase debris mobilisation risk:* Review silviculture regimes to determine whether current practices increase risk of slope failure and debris mobilisation, and develop techniques to reduce this risk.

(e) **Government guidance and support:**

(i) *Support from Te Uru Rākau – New Zealand Forest Service*: Te Uru Rākau to develop a slash management guide, and provide support to local authorities to ensure they have the resources and expertise needed to carry out effective compliance monitoring.

(ii) *Government support for indigenous afforestation:* Promote indigenous afforestation via amendments to the Emissions Trading Scheme ("**ETS**") and the development of a biodiversity incentive scheme.

(iii) *Government support for loss of land use:* If future regulations will result in a material loss of current land use, provide fair compensation to address this loss of asset value, and to assist forestry companies to cope with inability to utilise land.

(f) **Actively encourage transition of high-risk land**: Develop processes and timeframes that allow for the risk assessment of land, including the managed retirement of high-risk production forestry land and its conversion to other vegetative cover and provide mechanisms to incentivise this transition.

10. Further evidence supporting the above recommendations is set out in **Appendix 3** (an expert report produced by Brett Gilmore, Mike Marden and Rien Visser) and **Appendix 4** (a report on debris barriers, produced by Geobrugg).

The need for afforestation

Advantages of afforestation

11. Vegetation, especially forests, contributes to slope stability by reducing soil moisture (both through the canopy intercepting rainfall, and roots extracting moisture from the soil) and by reinforcing the ground through root systems.[4] As noted in **Appendix 1**, Tairāwhiti's unique and challenging terrain and environment mean that afforestation is key to addressing long-standing soil erosion issues in the area. Addressing soil erosion helps reduce landslides and debris flows, which contribute to the issue of mobilised woody debris and sediment.

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3 Strategically located land areas specifically set aside and enhanced to aggregate woody debris, that inevitably will enter waterways, before it creates a hazard to downstream property and where it can be efficiently managed.

4 Landslide Hazard and Risk at 517-519.

12. Further, a wealth of evidence exists to demonstrate that shrub/tree cover of some type on the Tairāwhiti landscape reduces sediment runoff and land slips that result in both soil and material on the land entering waterways.

Afforestation is only part of the answer

13. However, it needs to be acknowledged that the underlying geology in parts of the Tairāwhiti landscape is inherently weak and, irrespective of the forest regime (e.g. production or permanent exotic for carbon), the vegetation cover alone will not always prevent slope failure.

14. Consequently, it will be imperative that consideration is given to adopting a range of options for stabilising these weak landscapes, including:

    (a) Designation of some land for retirement, with reversion to a permanent indigenous forest cover. Aratu has a joint venture with eLandNZ that has been establishing indigenous forest, primarily around riparian zones and areas considered unsuitable for plantation forestry. Whilst in its infancy (100 hectares has been planted since 2021) this programme will continue and could be "put on steroids" with appropriate support mechanisms. For example, support to develop scale nurseries to reduce seedling cost, streamlining of consent processes, and enhancement via the ETS of ability to earn revenue from such plantings. We discuss below at [70] how indigenous afforestation could be accelerated through government support, including biodiversity credits.

    (b) the selection of other species (exotic or indigenous) able to be selectively harvested; and

    (c) passive management techniques that allow some of the worst affected areas to revegetate naturally.

Successful afforestation

Methods

15. A number of significant afforestation attempts have been made in the Tairāwhiti region, some more successful than others (addressed in **Appendix 2**). To achieve a lasting solution, it will be important to consider, and implement, a variety of methodical approaches, including both long-term and short-term measures.

16. The importance of such a specific and methodical approach is demonstrated by the history of Tairāwhiti land use, set out in **Appendix 2**. As evidenced there, the historical approach of planting forests on all available areas including near waterways and on the steepest slopes, and planting forests at the same time, may create problems in addition to solving some.

17. Learning from these previous projects, it would appear that the key factor for success is taking a tailored approach to afforestation, including by ensuring that all future afforestation:

    (a) takes into account relevant features of the land, such as water bodies, steepness of slope, and soil type;

    (b) is implemented in a planned manner, that is supported by independent and scientific research, to maintain slope stability through the presence of sufficient mature vegetation and forest at all times; and

(c) is supported by regulatory and commercial incentives that support the long-term nature of such a transition and the desired outcome of the project(s).

Tree type

18. Extreme weather events can affect both indigenous and exotic trees. The key factor as to the level of protection trees provide is the age of the tree, rather than the type.[5]

19. Therefore, it is important to consider the most appropriate kind of forest type and its purpose. In essence, consideration must be given as to which species will provide the best protection in certain areas. For example, longer rotation species, such as the Douglas fir and coppicing species, including coastal redwood, are particularly well suited to some high-risk sites.[6] This flexibility supports the tailored approach referred to above.

Steps towards afforestation

20. The overarching point is that, due to the instability of the land in Tairāwhiti, trees, through soil moisture reduction and soil reinforcement, continue to be the most cost effective and rapid stabilisation approach. This task will require significant investment, which is why Government and forestry companies will need to work together to ensure that as much of the riskier land can be covered as quickly as possible.

21. As observed in **Appendix 2**, the land use issue in Tairāwhiti is extensive; the resources within the Tairāwhiti region are insufficient to achieve a permanent solution with the urgency that is required; and resolving the issue will require government support either directly or via the development of market mechanisms to allow for projects to be funded.

22. Private companies, landowners, and investors need an economic reason to plant forests. The Government is incentivising forestry through the ETS and has used a broad brush to promote trees. However, if, for example, commercial forestry is banned on red zone country, and permanent exotics are banned from the ETS, then indigenous protection forestry remains as the only land use. Presently, revenue streams do not exist to support investment of this type because carbon accumulation does not cover the cost of establishment. Therefore, if afforestation of indigenous species on a broad scale is to be a solution, Government funding will be necessary due to the significant up-front investment that such an endeavour will require. Such funding will need to be available irrespective of whether the current use of the high-risk land is commercial forestry or agriculture. This is discussed further below at [70].

23. It is, however, significantly cheaper to prevent erosion than it is to fix damage caused by erosion. A 2001 study calculated that, at the time, the cost of preventing erosion would be $26 million annually, whereas the cost of addressing damage caused by erosion would cost $126 million annually.[7]

Wider benefits of afforestation

24. Afforestation in the Tairāwhiti region also has the following benefits:

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5 Landslide Hazard and Risk at 523.

6 Michael Marden, Donna Rowan, and Alex Watson "Effect of changes in forest water balance and inferred root reinforcement on landslide occurrence and sediment generation following Pinus radiata harvest on Tertiary terrain, eastern North Island, New Zealand" (2023) New Zealand Journal of Forestry Science 53:4 https://doi.org/10.33494/nzjfs532023x216x at 14.

7 Landslide Hazard and Risk at 533-534.

(a) Planting trees enables New Zealand to meet its requirements under the ETS, and, therefore, its international climate change commitments.

(b) Afforestation and forestry will continue to provide jobs and make a significant contribution to Tairāwhiti's economy. Given Tairāwhiti has limited productive land, for the reasons noted in **Appendix 1**, it is important for the region that land is utilised where it can be. Likely reflecting the difficulties with land use, Tairāwhiti had the second highest unemployment rate of all New Zealand regions at the end of 2022,[8] and severely reducing forestry activity will exacerbate this in the near term.

(c) Further, afforestation in Tairāwhiti can contribute to Māori employment success. Government should do all it can to support Māori economic resilience in the district. Tairāwhiti has one of the largest Māori populations in New Zealand – 52.9% of people in Tairāwhiti identified as Māori in 2018[9] – and 80% of the local forestry workforce identifies as Māori.[10]

Disadvantages of forestry sector afforestation

25. Although afforestation by the forestry sector contributes to land stability, ETS requirements and employment, it can also become a source of woody debris that can mobilise and impact downstream communities.

26. Plantation forestry companies need to rapidly adopt techniques to reduce the mobilisation of woody debris, so the benefits of the industry noted above can be achieved without causing harm to the community. Below we set out forestry management practices and debris management practices that will help reduce the impact of woody debris from forests impacting the community.

27. These practices combine prevention and mitigation measures. If a range of measures can be put in place across the management cycle, woody debris mobilisation and its impacts will be reduced.

Forestry Management Practices

Catchment limits and coupe harvesting

28. As noted above, forestry cover assists with slope stabilisation. Therefore, an issue that arises during the harvesting period is that if this cover is removed at a time when a severe storm occurs, the land is destabilised, leading to an increase in landslide occurrence[11] and the mobilisation of woody debris.

29. For forest stands that have already been planted, an effective way of responding to this problem is to develop:

(a) catchment or sub-catchment limits (which restrict the overall amount logged within a catchment in a defined period); and

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8 Figure NZ *Unemployment rate in New Zealand by region* https://figure.nz/chart/r9PsV2REYkH4yuj5-pJRjtp01mao0dErz.

9 Massey University *Regional differences in ethnic groups* https://www.ehinz.ac.nz/indicators/population-vulnerability/ethnic-profile/#:~:text=The%20M%C4%81ori%20population%20is%20concentrated,52.9%25)%20(Figure%201.

10 Tairāwhiti Regional Skills Leadership Group *Tairāwhiti Update,* February 2022 https://www.mbie.govt.nz/dmsdocument/18735-tairawhiti-update-february-2022.

11 Michael Marden, Donna Rowan, and Alex Watson "Effect of changes in forest water balance and inferred root reinforcement on landslide occurrence and sediment generation following Pinus radiata harvest on Tertiary terrain, eastern North Island, New Zealand" (2023) New Zealand Journal of Forestry Science 53:4 https://doi.org/10.33494/nzjfs532023x216x at 14.

(b) coupe harvesting limits and green up rules (which limit the extent of clearfelling in adjoining sections).

to ensure that there is sufficient vegetation and forest remaining to maintain slope stability.

30. Such an approach could, however, have financial implications on the viability of production forestry in certain areas of Tairāwhiti. Therefore, the key is to develop limits that ensure sufficient forest cover remains, while still enabling companies to harvest a sufficient volume of wood that will produce enough revenue to cover operating costs for access. Any other outcome would risk the operations of forestry companies, which would have significant flow-on impacts given their contribution to the Tairāwhiti region in terms of jobs as well as the wider economy.

31. Aratu considers that the best way to develop such limits would be by commissioning scientific, third-party research.

Recommendation 1: Commission an independent science-based approach to catchment limits and coupe harvesting limits.

Develop catchment or sub-catchment limits (which restrict the overall amount logged within a catchment in a defined period), and coupe harvest limits and green up rules (which limit the extent of clearfelling in adjoining sections) based on scientific, third-party research.

Best practice pre-harvest planning

32. Pre-harvest planning is key to ensuring that harvesting occurs in a way that protects both people and the environment. This is recognised, to some extent, by the Resource Management (National Environmental Standards for Plantation Forestry) Regulations 2017 ("**NES-PF**") which requires the development of both a "forestry earthworks management plan" and a "harvest plan".[12] In areas controlled by the Gisborne District Council ("**GDC**"), harvesting and associated activities are generally subject to a further set of requirements as set out in Resource Consents. However, these plans are quite high level and are developed for the purpose of demonstrating regulatory compliance.[13] Although they are required to identify and provide a proposed response to environmental risks, including slash,[14] they lack practical detail, including the "when" and "how" that are necessary for those on the ground.[15]

33. Therefore, the first step to mitigating and reducing slash is requiring forestry companies to develop a standard operating procedure for slash ("**SOP**"), which will provide step-by-step instructions to help forestry workers carry out operations so as to mitigate and reduce slash at every stage of the harvesting process. Adopting an SOP will ensure staff and contractors understand, and meet, the company's expectations around slash management.

34. The SOP should also include a robust harvesting risk assessment process to enable forestry workers to identify the risks that are specific to the land they are working on (above and beyond those that need to be addressed by the NES PF Harvest Plan and Resource Consents); address the potential on-site and off-site effects; and set out preventative and recovery controls. Examples of measures that could usefully be set out and explained in the SOP are noted below at [64]. The development of a best practice slash management guide by Te Uru

[12] Resource Management (National Environmental Standards for Plantation Forestry) Regulations 2017, sch 3.

[13] Brett Gilmore Consulting *Queen Charlotte Forest's Oyster Bay Catchment Harvest Plan*, July 2022 at 11.

[14] Resource Management (National Environmental Standards for Plantation Forestry) Regulations 2017, sch 3, cls 3, 5 and 6.

[15] Brett Gilmore Consulting *Queen Charlotte Forest's Oyster Bay Catchment Harvest Plan*, July 2022 at 11.

Rākau – New Zealand Forest Service, discussed below at [65], will also assist forestry companies with developing an effective SOP.

> **Recommendation 2: Apply best practice pre-harvest planning.**
>
> Support forestry companies to further develop their pre-harvest planning approaches. In particular, the creation of a standard operating procedure, detailing a robust harvesting risk assessment process that addresses onsite and off-site effects, and preventative and recovery controls. Te Uru Rākau could assist in providing support to companies and regulators in the development of techniques, standards and compliance processes.

Further develop regional forestry infrastructure standards

Types of infrastructure standards

35. Research notes that most countries which suffer from erosion problems utilise both "soft" and "hard" measures to deal with them – soft measures being afforestation, and hard measures being "hard engineering' mitigation measures" – but that New Zealand generally only focuses on afforestation.[16] Aratu has, since 2019, significantly increased the rigour with which infrastructure is designed, constructed and maintained. These measures are expensive but a significant step up from practices adopted pre-2018 within the estate. With the resilience of this infrastructure being demonstrated in recent years when intense storm activity has occurred, Aratu is increasingly confident that these adopted standards do reduce the risk of infrastructure failure, and subsequent debris mobilisation from such construction, to very low levels. Aratu suggests that the adoption of similar standards across the Tairāwhiti region, in addition to those contained in the Forestry Owners' Association Road Engineering Manual, would aid in the reduction of debris mobilisation. In particular:

(a) Standards should be set:

(i) for on-site roading and landings to ensure that they remain stable during extreme weather events;

(ii) as to the requirements for onsite slash and sediment measures, including water tables, cutouts, berms, culverts, flumes, sediment traps, soak holes, silt fences, sediment retention ponds, and crossings. Whilst the Forestry Owners' Association Forest Practice Guide contains high-level advice on these matters, the content is generic and forestry companies would be aided by more detailed information and adoption of greater levels of technical design appropriate to each specific situation; and

(iii) for earthworks, in particular, forestry companies should look to reduce the on-site landing earthworks footprint to help minimise landing failure.

(b) Forestry companies should be required to have an infrastructure maintenance programme and to regularly re-evaluate it to ensure that vulnerable structures are maintained consistently and in a timely manner.

[16] Landslide Hazard and Risk at 541-542.

Resilience of well-developed infrastructure

36. The value of well-developed infrastructure cannot be overestimated. Following the 2018 storms, Aratu reviewed and upgraded its existing infrastructure inherited from the previous owner and that company's practices. Following assessment of 760 landings and connected roading networks Aratu:

(a) Rehabilitated 308 landings so that they complied with the requirements of abatement notices that had been issued.

(b) Pulled additional slash back on 154 landings, and end hauled some of the slash to more stable and contained sites.

(c) Improved road drainage structures and road stabilisation, in accordance with civil and forest engineering best practice by:

(i) benching all works where fill needed to be contained and compacted;

(ii) compacting fill to consolidate it to a more stable and stronger state;

(iii) reducing fill slope angles (previously beyond the natural angle of repose);

(iv) reducing side cast construction (which uses the fill for construction without a bench) and increasing cut and fill construction;

(v) increasing end hauling to remove additional fill to more stable and contained sites;

(vi) utilising vegetation stabilisation of fills to reduce sheet wash erosion, like rilling;

(vii) increasing water controls, such as crossroad drains and flexiflumes, to reduce water volume and speed and help protect sensitive fill slopes; and

(viii) developing erosion and sedimentation structures to reduce erosion and trap larger sediment.

37. Improved construction practices result in a significant increase of costs up-front. For example, Aratu's road construction costs have tripled since 2018. However, better constructed infrastructure is much more resilient to the effects of storms. The evidence post the 2023 storms demonstrates that Aratu's upgraded roading and landing systems, and slash and sediment infrastructure measures, have held up very well and have prevented significant damage from occurring. Whereas in 2018 collapsed landings with debris discharges were a considerable problem, in 2023 landslides triggered by landing and road fill failures, and water control failures, such as successive blocked culvert inlets, have been relatively infrequent occurrences.

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Recommendation 3: Further develop regional forestry infrastructure standards.

Set standards for in-forest roading, waterway crossings, and landings, in addition to the standards contained in the Forestry Owners' Association Road Engineering Manual, to help ensure that they remain stable during extreme weather events, given the Tairāwhiti region's erosion issues. Also, expand on erosion and sediment control structure methods to help lessen risks associated with landslides commonly triggered through water control outlets, such as cutouts and culverts. Te Uru Rākau could assist in providing support to companies and regulators in the development of techniques, standards and compliance processes.

Improve in-forest management to reduce woody debris mobilisation risk

38. Although the above measures can reduce slash creation, it is inevitable that the harvesting process will result in some slash. Therefore, it is necessary to introduce measures, both short-term and long-term, to deal with slash post-harvest.

39. Both on-site and off-site slash management practices will need to be adopted, as it is very difficult to remove all of the slash off a hill (as you can in flat environments) due to the terrain type. Further, some slash cover provides for rainfall interception, thereby reducing erosion, and contributes to reduced sediment runoff.[17]

Address large woody debris on vulnerable areas

40. The first step to preventing harm from slash is addressing the amount of slash and woody debris left in vulnerable areas. This can be achieved by:

(a) reducing the amount of large woody debris left on landslide vulnerable areas;

(b) reducing the amount of large woody debris on or near all waterways;

(c) reducing the piece size limit, above which the material needs to be recovered to the landing; and

(d) ensuring that the woody debris that is removed is either stored in a safe storage place, such as a solid landing, or taken off-site.

41. By removing larger pieces of woody debris, and focusing particularly on vulnerable areas, there will be a reduction in both the amount of debris that will be mobilised by storms and extreme weather events, and the damage that it can cause.

42. It is important to acknowledge, however, that all debris that is removed will have to be physically removed either by people or machinery. As noted above, the steep terrain in Tairāwhiti makes it very difficult to extract all of it and to attempt to do so would give rise to health and safety concerns for forestry workers, and other potential adverse environmental effects.

43. An option that is currently being trialled by some forestry companies is a slash grapple, including specialised grapple attachments which improve the ability to remove slash from cutovers and creeks. This machinery enables large amounts of slash to be moved from harvest sites, near waterways and from landings, and creates less risk for forestry workers.

[17] Forest Owners Association *Forest Practice Guide 5.4 Vegetation to Manage Erosion* https://docs.nzfoa.org.nz/site/assets/files/1507/5-4_vegetation-to-manage-erosion_slash-2-0.pdf at 1.

44. However, there are also some limits on what slash grapples can achieve. First, slash grapples can only retrieve logs of up to a certain diameter, as if the diameter is too small the grapple will simply snap the stem. Second, the steep terrain in Tairāwhiti means that it may either be impossible to get such a machine to the woody material safely, or in a manner that would not cause damage to the surrounding environment.

45. Given slash grapples are a relatively new technology for New Zealand, time will be needed for them to be tested and, if successful, embedded. Aratu is currently meeting with manufacturers of slash grapples and if trials are successful will encourage its contractors to invest in slash grapples.

Recommendation 4: Address large woody debris on vulnerable areas.

Support forestry companies to reduce large woody debris left on landslide vulnerable areas to the extent that it is operationally possible.

Increase residue utilisation

46. Developing sustainable secondary industries that consume woody debris would aid with its removal. For example, options for it to be used for fuel or other bio materials would assist with the costs of processing and transporting. Potential avenues include: pellet fuels, biofuels hog fuel, and pyrolysis to create biochar. Aratu considers that both the industry and Government can collaborate to further investigate options for residue consumption.

47. It is especially important to explore residue consumption ideas within Tairāwhiti, for example, the utilisation of pellet fuel and biofuels at local facilities such as schools, hospitals and vegetable processing facilities. Local options are likely to be more economically feasible than exporting processed woody material outside of the region due to Tairāwhiti's relative isolation from main end users. Further, it also provides the opportunity for local economic benefits. Developing these options will inevitably take time and resources, but it is such long-term solutions that will best enable the efficient utilisation of some of the woody debris that causes downstream issues.

Recommendation 5: Increase residue utilisation.

Encourage the development of sustainable economically viable industries that consume woody residues from all sources.

Make it easier for companies to install and manage a range of debris retention mechanisms:

Why are debris nets (aka slash nets) necessary?

48. Although the above operational measures will significantly reduce the production and mobilisation of woody debris, it is impossible to control or remove it all, for the reasons noted at [42] and [44]. Therefore, it is important to also introduce secondary measures to deal with any residual debris, including that which eventuates from other sources e.g land slips unassociated with harvest operations, that has the potential to cause damage to the environment or housing and infrastructure.

49. As noted by Geobrugg, an international engineering company which specialises in geohazard and impact solutions: "Slash barriers are not designed to mitigate poor forestry practice but

are [a] useful tool in managing any waste material which was not able to be controlled at the source".[18]

How do debris nets work?

50. Debris nets are high-strength steel wire ring nets that can be placed around vulnerable sites, such as areas prone to land sliding and water bodies, to catch woody debris.[19]

51. The effectiveness of debris nets depends on:[20]

(a) **Retention volume**: Retention volumes can be maximised by utilising the topography of the land (ideally placing the debris nets on a straight section of river with sufficient bank height and/or at the entrance to a gorge or narrow section) and installing multiple barriers where the topography is difficult.

(b) **Protection and back-up mechanisms:** Ensuring that the debris nets that are installed have mechanisms to deal with multiple impacts, overtopping and erosion. For example, Geobrugg's debris nets have mechanisms to increase absorption capacity, and to concentrate overtopping debris flow material to the middle of the net, therefore avoiding overflow and erosion of the torrent banks.

(c) **Regular clearing:** Debris nets should be cleared out regularly to decrease the chances of them overtopping, which is why the location of the nets needs to be carefully considered.

52. The advantages of debris nets include that they:[21]

(a) are low in weight and have a short installation time so they can be installed on steep, difficult terrain without doing any damage to the environment;

(b) have low visual impact and produce significantly less carbon pollution when compared to a concrete check dam; and

(c) can easily be removed once they are no longer needed, or can be better positioned elsewhere.

International and domestic examples of debris nets

53. Debris nets are used internationally. For example, in the last ten years Geobrugg, an international engineering company which specialises in geohazard and impact solutions, has installed over 250 debris nets in more than 25 countries.[22] The following examples and pictures show how effective debris nets can be in protecting communities and the environment:

(a) **Peru**: In the Chosica region El Niño rains cause multiple mudslides and landslides. In February 2016, Geobrugg installed 22 debris nets across 9 valleys in the region. The following year, a 1 in 30-year storm hit the region. The barriers performed well

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18 Geobrugg New Zealand *Summary – Geobrugg slash/debris flow barriers*, 16 March 2023 at [1].

19 Geobrugg New Zealand *Summary – Geobrugg slash/debris flow barriers*, 16 March 2023 at [1].

20 Geobrugg New Zealand *Summary – Geobrugg slash/debris flow barriers*, 16 March 2023 at [1.1] and [1.2].

21 Geobrugg New Zealand *Summary – Geobrugg slash/debris flow barriers*, 16 March 2023 at [1.1].

22 Geobrugg New Zealand *Summary – Geobrugg slash/debris flow barriers*, 16 March 2023 at [1] and [3].

with two of them being filled to 95% capacity (10,000m^3), protecting the residential area below. (See pictures 1 and 2 below).[23]

(b) **Switzerland**: The Hüpach (or Huepach) barrier is the largest debris system in the world, being 40 metres wide and 10 metres high. It was installed to protect a settlement below which was highly endangered by debris flow and flooding.

54. Debris nets are also increasingly being installed in New Zealand. In 2021, the first dedicated debris net was established in Napier for an 800-hectare catchment; being 13.5 metres wide at the top, 8 metres wide at the bottom and 3.5 metres high.[24] In March 2022 it was filled for the first time and successfully contained a combination of slash and landslide material (see picture 3 below). The system was then cleared out and filled again in January 2023 (see picture 4 below) and in February 2023 (clearing did not occur in-between). Although the barrier was over topped, it remains intact (though as at time of writing it has only been inspected from the air due to road closures).[25]

Picture 1

Picture 2

23 Geobrugg New Zealand *Summary – Geobrugg slash/debris flow barriers*, 16 March 2023 at [3].

24 Geobrugg New Zealand *Summary – Geobrugg slash/debris flow barriers*, 16 March 2023 at [2].

25 Geobrugg New Zealand *Summary – Geobrugg slash/debris flow barriers*, 16 March 2023 at [2].

Picture 3

Picture 4

Current impediments to installing debris nets

55. Aratu considers that debris nets are a very effective supplementary measure for dealing with debris and that installing debris nets strategically within its forest estate will contribute significantly to the protection of the environment and the community. Debris nets are one of the few physical barriers that can be established straightaway and be immediately effective at arresting debris flows, when compared with vegetative barriers that require years to grow to a sufficient size and strength to be effective.

56. Debris nets are provided for in the NES-PF (referred to therein as slash traps). They can be either a "permitted activity" or a "restricted discretionary activity", which requires consent from the regional council.[26] Currently, most debris nets need to be consented as the NES-PF requires consent for any debris net located within the bankfull channel width of the river where "the catchment area upstream of the slash trap is greater than 20 ha".

[26] The Resource Management (National Environmental Standards for Plantation Forestry) Regulations 2017, regs 83-92.

57. In 2019, Aratu approached Geobrugg to provide a debris flow/driftwood barrier design for its Waimanu and Te Marunga sites. A system was designed that was "dimensioned to withstand a debris and slashing load including a dynamic puncturing load of a 15-tonne tree stem traveling at 10 m/s. The systems had edge protection to protect the top rope in the event they were over topped".[27]

58. Aratu applied for a Resource Consent from the GDC to obtain consent for these debris nets as designed. However, it took 4 years for the application to be considered, and cost Aratu in the vicinity of $100,000 on expert advice. Late 2022, the GDC notified Aratu that the project would need to go to public consultation, a process that would be funded by Aratu. Given the lack of progress and likelihood of further cost with no positive result, Aratu withdrew its application in December 2022.

59. In contrast, the Napier debris net, discussed above at [54], was applied for on 30 September 2021 and was granted on 15 November 2021 by the Hawkes Bay Regional Council ("**HBRC**").[28] No public consultation was required.[29] Instead, the consent imposed conditions that would protect the environment (largely reflective of the criteria laid out in the NES-PF for permitted debris nets), including that the debris net be:[30]

    (a) inspected every three months and within five days of significant rainfall events;

    (b) cleared of accumulated debris; and

    (c) installed in accordance with strict parameters to limit the environmental impact, including provision for the ongoing passage of fish.

60. The consent holder was also required to provide an annual report to the HBRC detailing the frequency of maintenance and clearance of the debris net, including photos, and any observations of blockages to fish passage; disturbance of the stream bed or banks; or damage to downstream property or infrastructure.[31]

61. Given the significant protection debris nets have been proven to provide to downstream communities elsewhere, Aratu considers that it is imperative that resource consent processes that enable debris nets to be implemented be developed with some urgency. The approach adopted by the HBRC provides a good example as to how the environmental impact can be considered, whilst still promoting the community's safety as a primary concern.

Debris Flow Barriers and Run off Areas

62. In addition to debris nets, Aratu recommends investigating the practicality of establishing a network of a variety of mechanical debris catchers in catchments of a full range of sizes. These structures may include:

    (a) rudimentary railway iron and wire rope structures on small or low risk catchments;

    (b) establishment of fast-growing tree species i.e. willows (Salix spp) strategically positioned to act as effective barriers, even if they topple; and

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[27] Geobrugg New Zealand *Summary – Geobrugg slash/debris flow barriers*, 16 March 2023 at [2.1].

[28] Hawke's Bay Regional Council *Resource Consent*, AUTH-127638-01, 15 November 2021 at 1 and 2.

[29] Hawke's Bay Regional Council Assessment of Resource Consent Application, AUTH-127638-01, 15 November 2021 at [8] and [11].

[30] Hawke's Bay Regional Council *Resource Consent*, AUTH-127638-01, 15 November 2021 at 2–4.

[31] Hawke's Bay Regional Council *Resource Consent*, AUTH-127638-01, 15 November 2021 at 4.

(c) engineered structures that can encourage the flow of debris being carried in rivers onto areas of land that are already effective natural repositories of some debris at times of flood. Aratu considers that there are areas of some farms adjacent to rivers that are relatively low value as farmland, which already attract woody debris deposits when floods occur, and that this feature could be enhanced at relatively low cost. From this position of concentration, efficient removal and processing of the debris could occur.

63. To facilitate this approach the ability to achieve consents for deliberate deposition, storage and disposal would need to be obtained. This may not be possible in the current regulatory environment.

Recommendation 6: Make it easier for companies to install and manage a range of debris retention mechanisms.

Develop resource consent processes that allow for engineered (e.g. debris nets) and non-engineered (e.g vegetative barriers and debris "run off" areas) retention mechanisms to be implemented via a clear and cost effective approval process.

Silviculture regimes and establishment practices

64. Silviculture regimes, including establishment practices, can increase the risk of debris mobilisation. Therefore, it is important to review silviculture regimes to determine whether the current practices increase risk of slope failure and debris mobilisation, and to develop techniques to reduce this risk. Silviculture techniques that can assist with reducing such a risk include:

(a) **Utilising up to date planning tools.** Until 2021, planning tools were unable to generate precise contours. The development of light detection and ranging mapping ("**LiDAR**") has revolutionised harvest planning as it can generate contours at 1 metre resolution, significantly increasing the ease and accuracy of forestry planning.[32] Aratu has used such techniques for several years and found LiDAR particularly useful for enabling:[33]

(i) the planning and construction of resilient harvesting infrastructure i.e. roads and landings, as it allows earthworks to be effectively implemented and minimised, leading to less runoff risk. In particular, limiting fill slopes to 30º prevents steep ground from being overloaded, which was what previously led to failures in old roads. (as noted above at [36]–[37] the Aratu forestry estate suffered less damage from the 2023 storms than the 2018 storms due to the improved landing and roading infrastructure);

(ii) the identification of areas:

(aa) of indigenous vegetation to ensure they remain untouched;

(bb) where mechanical felling can be carried out safely and effectively, preventing trees from being planted in sensitive areas; and

32 Brett Gilmore Consulting *Queen Charlotte Forest's Oyster Bay Catchment Harvest Plan*, July 2022 at 15.

33 Richard Rennie "Design shows Aratu Forests' impact reduction focus" *Farmers Weekly*, 3 February 2023 https://www.farmersweekly.co.nz/special-report/farms-forests-and-the-future/design-underpins-aratu-forests-impact-reduction-focus/.

(cc) that should be retired or left unharvested.

Further, combining LiDAR with a good geographical information system ("**GIS**") and design software provides topographical data on a scale which ensures much better land management than was previously possible. Particularly where planting stocking rates and thinning practices can be managed reflecting the variation in terrain and inherent risk.

(b) **Effective planting practices and strategies:** The following planting practices help slope stabilisation and protect vulnerable areas from slash and sediment:

(i) **Riparian planting using indigenous and introduced tree species:** Permanent vegetation needs to be strategically planted around water bodies (to minimise sediment and debris filling waterways.

As noted above, Aratu, via a joint venture with eLandNZ, is undertaking a long-term project to transition sensitive areas within the Aratu estate from pine to indigenous trees. The project aims to have sensitive areas within the estate planted with indigenous trees that, in time, will act as land stabilisers, silt filters and debris catchers.[34] Planting began in 2021, with 50 hectares established, and a further 50 hectares was established in 2022. This represents approximately 5% of the area harvested by Aratu each year.

It should be noted that riparian planting must occur in a thought-through, methodical way. Although planting trees around waterways reduces the amount of sediment entering the waterway, there is the potential for the trees to contribute woody debris to the waterways in the future if they are planted too close or not managed properly.

(ii) **Setbacks:** Production forests need to be set sufficiently far away from the riparian area and bodies of water to minimise them being filled with sediment and debris at harvest time. The NES-PF does set standards for setbacks (5 metres for rivers less than 3 metres wide and wetlands larger than 0.25 hectares; 10 metres for rivers greater than 3 metres wide, lakes larger than 0.25 hectares, outstanding freshwater bodies, water bodies subject to a water conservation order, or a significant natural area; and 30 metres for coastal marine areas).[35]

However, Aratu has found it more effective when replanting in the Tairāwhiti region to introduce setbacks of 10 metres for all water bodies, and 40 to 50 metres for large, incised gully systems. These large setbacks form some of the area that is established with indigenous trees via the eLandNZ project.

(iii) **Staggered harvesting:** As noted above, vegetation and forestry contribute to slope stability by removing soil moisture and providing reinforcement via roots. This makes it desirable to ensure that there are always sections of vegetation in place to improve slope stability. One way to achieve this is by harvesting in sections (discussed above), but a long-

[34] eLandNZ *The First Ground is Broken* https://www.elandnz.com/projects/the-first-ground-is-broken.

[35] Resource Management (National Environmental Standards for Plantation Forestry) Regulations 2017, reg 14.

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term solution is for forests in the same area to be planted at different times. By increasing the age class spread within a catchment, the need to harvest within a narrow time window will be relieved, as a wide age class spread will inevitably result in different harvesting times.

As noted at **Appendix 2**, one of the key issues with the post-Cyclone Bola response was the fact that the trees were planted within such a narrow time window that they all became due for harvesting within a similarly short window. This practice increased the risk of large areas of a catchment being harvested within a relatively narrow time frame, increasing the areas subject to the widely recognised high-risk post-harvest period.

(c) **Identification of highly erodible areas**: Identifying the extent and location of the most highly erodible areas at greatest risk of shallow landslide initiation, with the intention of transitioning these areas from a production forest to forest cover (exotic and/or indigenous forest) will mitigate landslide occurrence and the mobilisation of debris (discussed in detail below from [76]).

Recommendation 7: Ensure adopted silviculture regimes, including establishment practices do not increase debris mobilisation risk.

Review silviculture regimes to determine whether current practices increase risk of slope failure and debris mobilisation and develop techniques to reduce this risk.

Government guidance and support

Provision of a debris/slash management guide

65. Woody debris management is a complex issue. It requires a large degree of planning and foresight; the implementation of several different measures at a variety of stages; and effective evaluation and monitoring of those measures to make sure they are working as intended. Therefore, it is imperative that good guidance is provided to forestry companies so they can conduct their operations in the best way possible. Such guidance would also achieve consistency of practice and supplement each forestry company's SOP.

66. Aratu considers that Te Uru Rākau – New Zealand Forest Service is well placed to provide a debris/slash management guide that sets out what good practice looks like.

Support local authorities to have the resources and expertise to carry out effective monitoring

67. For standards and regulations to be effective, it is vital that they are monitored. Monitoring is the only way to ensure that compliance is occurring, and to determine whether enforcement action is necessary. In essence, you must inspect what you expect.

68. Therefore, local authorities must have both the resources and expertise needed to carry out effective monitoring. Currently, the GDC attends Aratu's forestry estate to monitor compliance with resource consent conditions. During 2021 and 2022 these visits averaged three per year. Aratu always finds these visits extremely helpful in ensuring that it is meeting the standards required. Since Aratu took over the forestry estate in 2019, the GDC has not issued any abatement notices or enforcement orders against Aratu.

69. Ideally, Aratu considers that the GDC should attend forestry estates no less frequently than quarterly to check for compliance. However, Aratu is aware that there are currently only two

personnel within the GDC who are responsible for monitoring compliance. This is not enough personnel to cover the Tairāwhiti region. Aratu considers that local authorities, such as the GDC, would be assisted by Te Uru Rākau – New Zealand Forest Service providing:

(a) additional resourcing, so more compliance officers can be employed; and

(b) education and training for compliance officers to ensure they have all the skills needed to provide effective monitoring.

Recommendation 8: Support from Te Uru Rākau – New Zealand Forest Service.

Te Uru Rākau to develop a slash management guide, and provide support to local authorities to ensure they have the resources and expertise needed to carry out effective compliance monitoring.

Support for indigenous afforestation

70. *Indigenous afforestation requires a significant up-front investment due to indigenous trees'* longer growth period and increased management needs. Reflecting this reality, the current ETS settings similarly incentivise the planting of exotic forests over indigenous forests. Consequently, to achieve successful indigenous afforestation further government support will likely be required.

71. Aratu considers that there are three potential avenues that could be explored further:

(a) amending the ETS to better account for the carbon that is contained within indigenous forests;

(b) providing capital to support native tree nurseries in local communities, and initiatives establishing indigenous riparian zones (such as eLandNZ); and

(c) developing a biodiversity incentive scheme, including biodiversity credits. Biodiversity legislation has already been introduced in the United Kingdom[36] and Australia is working on something similar.[37] In particular, the biodiversity scheme should strongly incentivise planting indigenous species on pre-1990 land, as currently the ETS settings prevent forests on pre-1990 land from qualifying for New Zealand Units.

72. In tandem with this approach, the ETS should be amended to relax carbon liabilities on pre-1990 forest land, where replanting indigenous tree species will meet the ETS thresholds for growth after a site is harvested.

Recommendation 9: Government support for indigenous afforestation.

Promote indigenous afforestation via amendments to the ETS and the development of a biodiversity incentive scheme.

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[36] Environment Act 2021 (UK) and https://www.pm.gov.au/media/biodiversity-certificates-increase-native-habitat-and-support-australian-landholders.

[37] Prime Minister, Minister for the Environment and Water *Biodiversity Certificates to Increase Native Habitat and Support Australian Landholders*, 26 August 2022.

Compensation in the event that regulations impose significant constraints

73. In the event that regulations are made imposing significant constraints on future land use, such as forced land retirement or restrictive catchment constraints, fair compensation reflecting the loss of current land use, including asset value, would be appropriate and fair.

74. In particular, where the regulations lead to a significant amount of a forestry estate being unable to be utilised over a period of time, the impact on forest owners could be significant and lead to viability issues. A lack of support could leave forestry companies, particularly smaller ones, struggling to continue operating, and is likely to swiftly have a negative impact on employment in the region.

75. Where the rules change and materially affect asset values without compensation this has the potential to reflect negatively on New Zealand as a destination for foreign investment. The precedent will likely impact a broader range of sectors that seek foreign investment than just forestry.

Recommendation 10: Government support for loss of land use.

If future regulations will result in a material loss of current land use, provide fair compensation to address this loss of asset value, and to assist forestry companies to cope with inability to utilise land.

Rehabilitation of land and managed retirement

76. Forestry management practices and slash management practices can largely address the issue of slope stabilisation and debris mobilisation. However, there are some types of geologies where the inherent land weakness makes it very difficult, and in some cases impossible, for vegetation and forestry to prevent slopes from falling, for example, steep incised gullies.

77. Therefore, it will be necessary to develop processes and timeframes that allow for the risk assessment of land, and the rehabilitation or retirement of high-risk land. In particular, for areas designated high-risk it will be necessary to develop a strategic retreat plan, which may include the planting of longer lived or indigenous production species, or, in severe cases, land being taken out of production and retired.

78. Developing a strategic retreat plan takes time, as a number of steps need to be worked through, including:

(a) Mapping the terrain of the forestry estate via a terrain attribute extraction process. Such a process considers slope, elevation, aspect, geology, a range of terrain metrics, and some climate data.

(b) Using the above data to create:

(i) a model of the landslide susceptibility risk across the forestry estate using appropriate modelling techniques, such as the Melton ratio; and

(ii) land use capability maps, which will then be used by a geoscientist to develop operational-scale erosion susceptibility ("**ESC**") maps. ESC maps provide a highly detailed and accurate depiction of the high and very high erosion susceptibility parts of the forestry estate. Although Te Uru Rākau – New Zealand Forest Service currently has ESC maps, they are not sufficiently specific to enable the detailed assessment required to manage landslide risks in these difficult areas.

(c) Using the above modelling and maps to develop a land use optimisation matrix or tool to inform future land management decisions and techniques to reduce risk.

79. Aratu started this process in August 2021, and it is still ongoing, partially due to the disruption caused by the 2023 storms. Therefore, any recommendations relating to rehabilitation and retirement of land would need to take into account the need to conduct such processes, and the fact that they require a significant amount of time.

80. Additionally, any retirement of high-risk areas should ideally only occur once these areas had been harvested a last time. This reflects the fact that "leaving larger areas of plantation on high or extremely risky sites is unlikely the best long-term risk management alternative to harvesting from an economic, environmental and social perspective".[38] However, there may be site specific areas that are best left unharvested, such as streamside management areas with steeply incised gullies, where the stand provides stability, and the ability to both trap mobilised sediment and woody debris. Further, harvesting should not occur on high-risk areas where this would create a health and safety risk to workers.

Recommendation 11: Actively encourage transition of high-risk land.

Develop processes and timeframes that allow for the risk assessment of land, including the managed retirement of high-risk production forestry land and its conversion to other vegetative cover and provide mechanisms to incentivise this transition.

[38] Brett Gilmore Consulting *Queen Charlotte Forest's Oyster Bay Catchment Harvest Plan*, July 2022 at 27.

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APPENDIX 1

Tairāwhiti's geology, topography, climate, and indigenous forest clearance

Geology

1. Land use in Tairāwhiti is a complex issue, due to the land in the East Coast region being "severely erodible".[39] Whereas only 8% of land in New Zealand is "susceptible to severe erosion", 26% of the land in the Tairāwhiti district meets this criteria.[40] Of all New Zealand regions, Tairāwhiti has "the highest proportion of its area classified as highly erodible land at risk of erosion" – 1,377km² (137,700 hectares) – comprising 16% of its area.[41] As a consequence, Tairāwhiti also has "the greatest area in New Zealand with severe earthflow risk (235km²) and gully risk (162km²)".[42] Due to forestry's use as an erosion control mechanism, the proportion of forest estates in these susceptible classes is significantly higher than the region's average.

2. The Parliamentary Commissioner for the Environment has noted that the East Coast's geology has a "predispos[ition] towards rapid or accelerated erosion" given the two main rock types – mudstones and argillites – are "inherently unstable".[43] This instability is further concentrated in the southern and eastern areas, which are dominated by younger rocks of Tertiary age (soft mudstones, sandy mudstones, sandstones and limestones).[44] In contrast to the northern and western areas, which are dominated by older rocks of the Cretaceous age (fractured argillites, greywackes and basalt).[45] This difference will be important when considering measures that can be introduced to improve land use outcomes.

Topography

3. In addition to soils that are prone to erosion, the land in Tairāwhiti is also characterised by "moderately steep to very steep, dissected terrain".[46] Steeper slopes are more prone to landslides. For example, a study conducted after the 2018 storms in Te Marunga Forest, which has a majority of slopes between 25º to 35º (for context, slope groups are 0-6º, 6-16º, 16-20º, 20-25º, 25-35º and 35+º), found that 75.5% of the landslides occurred on slopes greater than 35º, with a further 16% of landslides occurring on slopes between 25-35º.[47] In comparison, only 2% of landslides occurred on slopes between 0-6º.[48]

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[39] Chris Phillips and Michael Marden "Reforestation Schemes to Manage Regional Landslide Risk" in Thomas Glade (ed) *Landslide Hazard and Risk* (John Wiley & Sons Ltd, West Sussex, 2005) 517 at 524 ["**Landslide Hazard and Risk**"].

[40] MPI Erosion Control Funding Programme (ECFP) for the Gisborne district, 19 September 2021 https://www.mpi.govt.nz/forestry/funding-tree-planting-research/closed-funding-programmes/erosion-control-funding-programme/.

[41] Stats NZ Tatauranga Aotearoa *Highly erodible land*, 18 April 2019 https://www.stats.govt.nz/indicators/highly-erodible-land.

[42] Stats NZ Tatauranga Aotearoa *Highly erodible land*, 18 April 2019 https://www.stats.govt.nz/indicators/highly-erodible-land.

[43] Parliamentary Commissioner for the Environment *Sustainable Land Management and the East Coast Forestry Project* (Office of the Parliamentary Commissioner for the Environment, Wellington,1994) at 6.

[44] Landslide Hazard and Risk at 524.

[45] Landslide Hazard and Risk at 524.

[46] Parliamentary Commissioner for the Environment *Sustainable Land Management and the East Coast Forestry Project* (Office of the Parliamentary Commissioner for the Environment, Wellington,1994) at 6.

[47] Dr Mike Marden *Preliminary findings on factors contributing to sediment/slash generation and transport during storm events on 3-4 and 11-12 June 2018, part Te Marunga Forest, Mangatokerau Catchment,* July 2018 at 11 ["**2018 Marden Report**"].

[48] 2018 Marden Report at 11.

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Climate

4. As well as having a difficult landscape, the Tairāwhiti area is "susceptible to severe storm events and occasionally to cyclones, which contribute to the incidence of erosion".[49] There has been a "high frequency in events" in the region with storms in "1975, 1980, 1982, 1988 [Cyclone Bola], 2002, 2005, 2011, 2015, three storms in 2017, two in 2018.[50] This year has seen two further cyclones, Hale (January 10th) and Gabrielle (February 14th). It has been predicted that the climate for the East Coast will include "more frequent extratropical cyclones with associated higher intensity rainfall".[51]

5. Given Tairāwhiti's unstable geography and topography, "heavy or prolonged rainfall" acts as a "triggering event" to mass movement or landslides.[52] Essentially, exceptional rainfall permeates through the erosion-prone coverbed materials, adding to the water beneath the land surface (known as subsurface water), and causing an increase in pressure within the coverbed materials (known as pore water pressure).[53] Eventually, the pressure will increase to a point where the materials liquefy and fail; compounded by the fact that soils on slopes over 26º become unstable as they approach saturation.[54]

6. It is hard to identify a set threshold of rainfall that will trigger a landslide, but it has been noted that, generally, an excess of 200mm over a few days leads to "significant regional landsliding events in New Zealand soft-rock hill country".[55] Once triggered, landslides and debris flows begin as small streams of water heavily laden with soil and woody debris, with a transporting power disproportionate to their size.[56] These debris flows occur on both pastural and forested land to varying extents. Debris flows from commercial pine plantations entrain many sources of woody residues, including younger trees in their entirety (as occurs with younger tracts of indigenous forest), harvesting residue (slash), and older trees that have blown over for reasons not associated with harvesting.

Indigenous forest clearance

7. The above environmental factors which predispose a region to erosion and landslides can be mitigated by the presence of vegetation, especially forest.[57] However, the Tairāwhiti region has a lack of vegetation, reflecting the fact that between the 1880s and 1920s European settlers cleared all the existing forest for pastoral production. During that period, there was no land clearance policy in place stating what could be cleared and where. Consequently, the settlers cleared as much of the forest as they could, often with government support, without realising that severe consequences would follow. Despite warnings by geologists at the time, clearance continued well into the 1920s by which point there was very little forest left standing.

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49 Landslide Hazard and Risk at 526.

50 2018 Marden Report at 4.

51 2018 Marden Report at 4.

52 Landslide Hazard and Risk at 522.

53 2018 Marden Report at 16.

54 2018 Marden Report at 16.

55 Landslide Hazard and Risk at 522.

56 2018 Marden Report at 22; and Michael Marden, Donna Rowan, and Alex Watson "Effect of changes in forest water balance and inferred root reinforcement on landslide occurrence and sediment generation following Pinus radiata harvest on Tertiary terrain, eastern North Island, New Zealand" (2023) New Zealand Journal of Forestry Science 53:4 https://doi.org/10.33494/nzjfs532023x216x at 13.

57 Landslide Hazard and Risk at 517 – 519.

Relevance for Inquiry

8. The environmental factors set out above demonstrate that land users in Tairāwhiti face a unique set of challenges. Any recommendations made by the Inquiry will need to take into account these specific regional challenges to ensure successful outcomes across all land uses.

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APPENDIX 2

Historical response to land use issues

1940s-1988

1. In the early 1940s, the impact of soil erosion and sediment deposition on East Coast pastoral lands and rivers became evident.[58] Consequently, the Government began introducing a variety of measures in an attempt to address these issues:

   (a) In 1941, the Soil Conservation and Rivers Control Act was passed, and catchment boards were instituted to "manage and prevent soil erosion".[59]

   (b) In 1944, the Poverty Bay Catchment Board was formed and by 1948 it had established a large-scale reforestation trial. The trial proved successful in slowing eroding gullies, but unsuccessful in stabilising riverbeds and gullies by check-dams as they became filled with sediment. The partial success of these early trials led to the Soil Conservation and Rivers Control Council (set up in 1955) "urg[ing] the New Zealand Government to purchase eroding farmland to establish dual-purpose exotic forests, for protection against erosion and for production of timber".[60]

   (c) In 1959, Cabinet approved an "erosion control scheme". The New Zealand Forest Service ("**NZFS**") was "to acquire and reforest 7000 ha of the most severely eroding country in the upper Waipaoa River catchment", with an estimated cost of NZ£1,240,000. Planting began in 1960 and resulted in the Mangatu Forest.[61]

   (d) In 1963, the Government established a Committee of Inquiry to "inquire into the conservation problems of Poverty Bay-East Cape (an area covering some 600,000 hectares) and to make recommendations on a comprehensive control programme".[62] The resulting report (known as the Taylor Report) acknowledged that "the immense erosion problems were beyond the resources of the farming community and required substantial taxpayer help",[63] with the Committee stating:[64]

   > Where such erosion has developed on a grand scale the cost of erosion control would far exceed the value of pastoral production from the land concerned. There is, therefore, no known way of economically controlling erosion of this kind other than by the complete afforestation of the catchment concerned.

   (e) In 1968, in response to the Taylor Report, the Government introduced the 'Blue Line' approach, which instituted two measures:[65]

      (i) The "East Coast Project", for land at severe risk of erosion. The programme required the NZFS to "progressively plant the unforested parts

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[58] Landslide Hazard and Risk at 528.

[59] Landslide Hazard and Risk at 528.

[60] Landslide Hazard and Risk at 528.

[61] Landslide Hazard and Risk at 529.

[62] Technical Committee of Inquiry into the Problems of the Poverty Bay-East Cape District of New Zealand *Wise Land Use and Community Development* (1970, Wellington, Ministry of Works and Development) at 1 ["**The Taylor Report**"].

[63] Landslide Hazard and Risk at 529.

[64] The Taylor Report at 5.

[65] Landslide Hazard and Risk at 529.

of the [land at severe risk of erosion] with dual-purpose protection/production forests". This planting continued until 1987 when the NZFS was corporatised.

(ii) A government subsidy for on-farm soil conservation works, for land at less severe risk of erosion.

(f) In 1978, following dissatisfaction with the generality of the 'Blue Line' approach, the Poverty Bay Catchment Board (at this point the East Cape Catchment Board) proposed four new categories in the 'Red Report'. However, the NZFS continued to plant in conformity with the Blue Line approach.[66]

(g) In 1987, the corporatising of the NZFS (to become the Forestry Corporation) led to the East Coast Project ending. Despite the fact that the Minister of Works and Development noted the need for the Corporation to be subsidized to continue carrying out this work, interim funding was only provided until 1987. From 1968 to 1987, 36,100 hectares had been acquired and planted by the NZFS, with an additional 1809 hectares established through forest encouragement grants. The total costs were estimated at $229 million.[67] The East Coast Project Review acknowledged that the afforestation targets had not been met, but concluded that, contrary to the Taylor Report, erosion was no longer a critical problem. This optimistic assertion was proven to be false following Cyclone Bola.

1988 (Cyclone Bola) to 2018

2. In spite of the Government's extensive afforestation efforts, Cyclone Bola (6-9 March 1988) – during which 900mm of rain fell in 72 hours – caused "widespread severe landsliding, erosion, flooding and siltation".[68] Pastoral land suffered badly, with some slopes losing 70% or more of their grass cover.[69] However, landslides were less frequent on "hillslopes protected by mature indigenous forest and older pine forest".[70]

3. Studies arising out of Cyclone Bola concluded there was "little difference in the protective value between different forest types, for example indigenous forest or exotic plantation forests", however, "forest age ha[d] a significant effect on the number of landslides".[71] For example:

(a) "forest stands older than 8 years sustained ten times less damage than did stands younger than six years old"; and[72]

(b) "fully stocked stands of mānuka and kānuka provided a greater level of protection against the initiation of landslides than did 6–8-year-old stands of exotic forest but were less effective than exotic forest >8 years old".[73]

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[66] Landslide Hazard and Risk at 530.

[67] Landslide Hazard and Risk at 530.

[68] Landslide Hazard and Risk at 531.

[69] Landslide Hazard and Risk at 531.

[70] Landslide Hazard and Risk at 531.

[71] Landslide Hazard and Risk at 523.

[72] Landslide Hazard and Risk at 532.

[73] Michael Marden, Donna Rowan, and Alex Watson "Effect of changes in forest water balance and inferred root reinforcement on landslide occurrence and sediment generation following Pinus radiata harvest on Tertiary terrain, eastern North Island, New Zealand" (2023) New Zealand Journal of Forestry Science 53:4 https://doi.org/10.33494/nzjfs532023x216x at 14.

4. Following Cyclone Bola, the East Coast Conservation Forestry Scheme was set up with the Government contributing $8 million, and the East Cape Catchment Board providing the remaining one-third.[74] The fund was aimed at establishing 3000 hectares of protection forest per year for five years, with covenants precluding logging for at least 25 years after planting and then only with the permission of the local catchment authority.[75] The Government's investment in such a scheme reflected:[76]

(a) The extent and severity of the erosion being much greater than in any other New Zealand region and its "substantial negative impact on the region's social and economic development".

(b) The need for swift erosion control to reduce future costs of erosion and flood damage both to the region and to the Government.

(c) The fact that there was insufficient money and resources within the region to institute a comprehensive erosion control scheme.

5. In 1992, the East Coast Forestry Project ("**ECPF**") was announced. The ECFP, administered under the Forestry (East Cost) Grant Regulations, aimed to improve erosion across the whole region (rather than just targeting specific catchments); with planting beginning in 1993.[77] In 2000, new regulations were introduced, which stated the aim of planting "200,000 ha over 28 years (1992-2020)" with "a planting rate of 70,000 ha per year and a maximum annual budget of $6.5 million".[78] In 2014, the ECPF was renamed the Erosion Control Funding Programme ("**ECPF 2**"),[79] and the funding continued until 2018 when the ECPF 2 land treatment grants were discontinued, though funding for community projects addressing erosion continue.[80]

2018 storms

6. In June 2018, severe storms once again hit Tairāwhiti, resulting in landslides and debris flows. The Council's rainfall data suggests that the rainfall in the area of Aratu's Te Marunga Forest during 3–4 June 2018, was a more than a 1-in-100-year event with downpours as heavy as 55mm per hour for three to four hours resulting in 155mm to 210mm of rainfall just during that period. During the period 3–9 June 2018, the maximum rainfall recorded was 362.5mm at Pakarae Station, south of Te Marunga Forest. The average rainfall across 44 rain stations was 143.3mm. For the week of 11 June 2018, rainfalls averaging 114mm fell over three days. A maximum rainfall of 257mm was recorded in one location.

7. These storms hit just shortly after a number of forest stands had been harvested (reflecting the fact that they had predominantly been planted after Cyclone Bola and were at an age where they were due to be harvested).[81] The resulting lack of vegetation, therefore, contributed to the level of landsliding and debris.[82]

[74] Landslide Hazard and Risk at 532.

[75] Landslide Hazard and Risk at 532.

[76] Landslide Hazard and Risk at 532.

[77] Landslide Hazard and Risk at 532.

[78] Landslide Hazard and Risk at 532.

[79] Beehive *Changes to East Coast erosion grant scheme*, 31 July 2014 https://www.beehive.govt.nz/release/changes-east-coast-erosion-grant-scheme.

[80] MPI *Erosion Control Funding Programme (ECFP) for the Gisborne district*, 19 September 2021 https://www.mpi.govt.nz/forestry/funding-tree-planting-research/closed-funding-programmes/erosion-control-funding-programme/.

[81] 2018 Marden Report at 2 and 6.

[82] 2018 Marden Report at 24.

Expert Report on land use issues in Tairāwhiti and forestry management practices in response

Brett Gilmore[1], Mike Marden,[2] and Rien Visser[3]

Effectiveness of afforestation in reducing erosion

1. The understanding of how vegetation contributes to slope stability and erosion control is well advanced. A closed canopy forest cover contributes to an increase in slope stability and a significant reduction in erosion by reducing the ability of rainfall to cause slope failure through the processes of interception and evapotranspiration, while the roots provide mechanical reinforcement and are how trees extract moisture from the soil to reduce pore water pressures. These processes become most effective after branches of individual trees touch (canopy closure) and lateral roots of adjacent trees overlap (full-root occupancy). The rate at which canopy closure and root occupancy occur is largely determined by plant spacing, growth rate and silviculture (tree tending) regimes.

Shallow landslides

2. Trees help reduce the frequency of shallow landslides. Soils under a closed canopy forest are less prone to rainfall-induced landslides than similar soils under pasture, or if the canopy is more open, such as in young stands of pines and scattered, regenerating scrub.

   (a) During Cyclone Bola, areas under closed canopy indigenous forest and exotic plantations older than 8-years were:[4]

      (i) 16 times less susceptible to landsliding than pasture and exotic pines less than 6-years old; and

      (ii) four times less susceptible than closed canopy regenerating scrub (age unknown) and exotic pines 6-8-years old.

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[2] Dr Mike Marden is a retired scientist with extensive knowledge of the extent and scale that geological influences and geomorphological processes, over geological time scales, have had on landscape development within the East Coast Region (Tairāwhiti) of New Zealand. He has researched the landscape's response to storm events, reforestation/deforestation cycles, and evaluated the effectiveness of erosion mitigation strategies required to underpin land use change and sustainability. Mike has international experience as a consultant to the Food and Agricultural Organisation (FAO) and has worked extensively with NZ government agencies, Councils and forest companies.

[3] Rien Visser is a Professor at the University of Canterbury, and is responsible for Forest Engineering at the School of Forestry. In addition to teaching, he has completed many harvesting and infrastructure related research projects over time. He also teaches outreach courses on aspects such as Forest Roads and Stream Crossing, Cable Logging Planning, and Harvest Residues. After the Queen's Birthday storm event, the Gisborne District Council used Rien's services to support their evaluation of forest practices in the region, and subsequently used him as an expert witness to support legal proceedings under the RMA.

[4] Marden, M, & Rowan, D. (1993): Protective value of vegetation on Tertiary terrain before and during Cyclone Bola, East Coast, North Island, New Zealand. New Zealand Journal of Forestry Science, 23(3), 255-263.

(b) In an East Coast study of landslide damage to fully stocked stands of reverting kānuka and manūka scrub of known age, damage to 10-year-old stands was estimated to be 65% less than that sustained by pasture and 90% less in 20-year-old stands.[5]

(c) Following the Manawatu storm,[6] landsliding under forest was 90% less than that under pasture and 80% less than that under scrub.[7]

An example of the effectiveness of a closed canopy of exotic forest in protecting slopes against storm-initiated landslides. An estimated 80% of the pastured slope was impacted by landslides.

3. Comparisons of storm-initiated landslide densities for different vegetation types shows that there is little difference in the protective value between closed-canopy evergreen forest species, but that forest age has a significant effect on the intensity of landslides initiated.

4. However, there are differences between trees species and their ability to bind the soil, due to root-system dimensions and the degree of root-soil reinforcement. For example, research has shown differences in the root systems of kānuka and *P. radiata.* The roots of individual kānuka are smaller than those of *P. radiata* at all stages of growth, however, the difference in total root mass is compensated for by the higher natural stand densities of the kānuka. Furthermore, the annual rate of root production in stands of regenerating kānuka exceed that of *P. radiata* for the first nine years of growth.[8] Research shows that a dense

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[5] Bergin, D. O; Kimberley, M.O.; Marden, M. (1995). How soon does regenerating scrub control erosion? New Zealand Forestry, August 1993.

[6] Marden, M. (2004). Future-proofing erosion-prone hill country against soil degradation and loss during large storm events: have past lessons been heeded? New Zealand Journal of Forestry, 49, 11-16.

[7] Dymond JR, Ausseil AG, Shepherd JD, Buettner L (2006). Validation of a region-wide model of landslide susceptibility in the Manawatu-Wanganui region of New Zealand. Geomorphology 74, 70–9.

[8] Watson, A., Marden, M., & Rowan, D. (1994). Tree species performance and slope stability. In D.H. Barker (Ed.), Proceedings of Institute of Civil Engineers Conference, "Vegetation and Slopes – Stabilisation, Protection and Ecology". 29-30 September 1994, University Museum, Oxford, United Kingdom (pp. 161-171). https://doi.org/10.1680/vasspae.20313.0018

stand of regenerating kānuka was less likely to fail than similar slopes in *P. radiata*, at least for the first nine years after establishment. Thereafter, older aged stands of both species afforded a high and comparable level of slope resistance against landslide initiation.[9]

Earthflows

5. Similarly, trees can reduce the rate of earthflow displacement primarily through reduced soil water content. In general terms, the denser the planting, the greater the probability of successfully stabilising earthflows. Depending on planting density and growth rate, canopy closure within pine plantations occurs within eight years. By then, the soil water content of forested earthflows is drier for longer periods than for unforested earthflows and, consequently, the rate of displacement slows appreciably.[10]

Active earth flow complex before (left) and after (right) reforestation. Rates of downslope earth flow movement declined by an order of magnitude within the period of a rotation of pines around 27 years.[11]

Gully erosion

6. The reforestation of gullies is the most practical and effective means of stabilising all but the largest of gullies. At both regional and catchment scale, the magnitude in the reduction in gully-derived sediment yield following the afforestation of gullies, relative to the yield had no afforestation been undertaken, has been substantial.[12]

7. Gully erosion is prevalent in many Tairāwhiti catchments with most gullies formed after the clearfelling of the original indigenous forest. Although gully erosion (a fluvially-driven process), as of 2017, affects just around 0.6% of the region's hill country area, gullies collectively generate the highest proportion of the sediment load,[13] and of the annual

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[9] Ekanayake, J.C., Marden, M., Watson, A.J., & Rowan, D. (1997). Tree roots and slope stability: a comparison between P. radiata and kānuka. New Zealand Journal of Forestry Science, 27(2), 216-233. https://www.scionresearch.com/__data/assets/pdf_file/0009/59508/NZJFS2721997

[10] Pearce, A.J., O'Loughlin, C.L., Jackson, R.J., & Zhang, X.B. (1987). Reforestation: on-site effects on hydrology and erosion, eastern Raukumara Range, New Zealand. Forest Hydrology and Watershed Management (pp. 489-497). [Publication 167]. International Association Hydrological Sciences, Proceedings of the Vancouver Symposium.

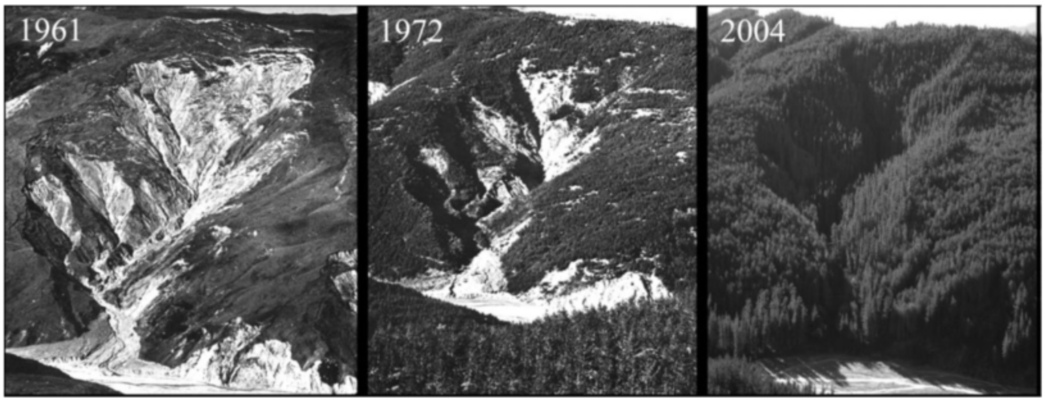
[11] Photo from Marden, M. (2004). Future-proofing erosion-prone hill country against soil degradation and loss during large storm events: have past lessons been heeded? New Zealand Journal of Forestry, 49, 11-16.

[12] Herzig, A., Dymond, J.R., & Marden, M. (2011). A gully-complex model for assessing gully stabilisation strategies. Geomorphology, 133, 23-33. https://doi.org/10.1016/j.geomorph.2011.06.012

[13] Marden, M., Betts, H., Arnold, G., & Hambling, R. (2008). Gully erosion and sediment load: Waipaoa, Waiapu and Uawa rivers, eastern North Island, New Zealand. In J. Schmidt, T. Cochrane, C. Phillips, S. Elliott, T. Davies, L. Basher (Eds.), Sediment dynamics in changing environments (pp. 339-350). [Publication 325.] Wallingford, Oxfordshire, UK: International Association of Hydrological Sciences; and Herzig, A., Dymond, J.R., & Marden, M. (2011). A gully-complex model for assessing gully stabilisation strategies. Geomorphology, 133, 23-33. https://doi.org/10.1016/j.geomorph.2011.06.012.

sediment yield discharged to the marine environment from each of the major catchments in this region.[14]

8. Research on the effectiveness of exotic forest in stabilising gullies shows that the time required to 'shut down' a gully is strongly associated with the gully's size at the time of planting. Both Tertiary and Cretaceous terrain gullies of equivalent size take a similar time to stabilise.[15] Also, linear gullies are likely to stabilise earlier than their larger amphitheatre-shaped counterparts.



Severely degraded gully stabilised by planting exotic pines.[16]

9. Unfortunately, although attempts at gully remediation since the early 1960s have resulted in a 45% reduction in gully numbers, by 2017 the current area of hill country affected by gullying was only 5% less than 60 years ago. During this period, gully initiation and development have outstripped mandated erosion control targets set by the East Coast Forestry Project (**ECFP**), for land designated as LO3A, and for the 'Restoration of the Waiapu Catchment' by 2020-2022.[17]

10. While acknowledging the role of exotic forests in effectively stabilising gullies 1-10 hectares in size, for gullies identified in the National Environmental Standard for Plantation Forestry (**NES-PF**) as high erosion risk (orange zone) or where the erosion risk is very high (red zone), experts have recommended:[18]

    (a) a revision of remediation strategies for the larger and more actively eroding of gullies destined for future afforestation; and

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[14] Hicks, D.M., Shankar, U. (2003). Sediment from New Zealand rivers. NIWA Chart, Miscellaneous Series no. 79. National Institute of Water and atmospheric Research, Wellington, New Zealand.

[15] Marden, M., Arnold, G., Gomez, B., & Rowan, D. (2005). Pre- and post-reforestation gully development in Mangatu Forest, East Coast, North Island, New Zealand. River Research and Applications, 21, 1-15. https://doi.org/10.1002/rra.882; and Marden, M., Arnold, G., Seymour, A., & Hambling, R. (2012). History and distribution of steepland gullies in response to land use change, East Coast Region, North Island, New Zealand. Geomorphology, 153-154, 81-90. https://doi.org/10.1016/j.geomorph.2012.02.011.

[16] Marden, M., Arnold, G., Gomez, B., & Rowan, D. (2005). Pre- and post-reforestation gully development in Mangatu Forest, East Coast, North Island, New Zealand. River Research and Applications, 21, 1-15. https://doi.org/10.1002/rra.882.

[17] Marden, M., & Seymour, A. (2022). Effectiveness of vegetation mitigation strategies in the restoration of fluvial and fluvio-mass movement gully complexes over 60-years, East coast region, North Island, New Zealand. New Zealand Journal of Forestry Science 52:19. https://doi.org/10.33494/nzjfs522022x226x.

[18] Marden, M., & Seymour, A. (2022). Effectiveness of vegetation mitigation strategies in the restoration of fluvial and fluvio-mass movement gully complexes over 60-years, East coast region, North Island, New Zealand. New Zealand Journal of Forestry Science 52:19. https://doi.org/10.33494/nzjfs522022x226x.

(b) for gullies within exotic production forests, the replanting of species (exotic or indigenous) better suited to providing long-term stabilisation, post-harvest.

11. In the long term, if all 1800 gullies that currently remain untreated – but are treatable – were to be afforested in a timely manner, the expected reduction in sediment generation would result in a decline in the rate of bed load aggradation of the major river systems,[19] with potential off-site benefits including:

(a) a reduction in the cost of bridge replacement and road repairs;

(b) almost eliminating expensive channel excavation, realignment and/or stopbank construction; and

(c) a likely reduction in the incidence of flooding of low-lying, high-value farmland.

Actively eroding gully located within a P. radiata production forest. Forest removal before significant groundcover vegetation has established within the most active part of the gully will probably result in the remobilisation of sediment and woody debris by storms following future harvests.[20]

Relevance to Tairāwhiti

12. The Tairāwhiti region has a severe problem with highly erodible soil. The continued loss of soil from significant areas of the Tairāwhiti region resulted in the most affected intensive pastoral farming areas changing land use to plantation forestry. Plantation forests were initially established to control erosion in areas where conservation efforts on pastoral land since the 1940s had proved ineffective. During the past 60 years, a significant number of

[19] Peacock, D.H., Marden, M. (2019). Mean bed level trends in the upper Waipaoa river channel and Te Weraroa stream in response to land use change: 1948 to 2019. Prepared for Gisborne District Council.

[20] Marden, M., & Seymour, A. (2022). Effectiveness of vegetation mitigation strategies in the restoration of fluvial and fluvio-mass movement gully complexes over 60-years, East coast region, North Island, New Zealand. New Zealand Journal of Forestry Science 52:19. https://doi.org/10.33494/nzjfs522022x226x.

extreme storm events have resulted in continued mass erosion and significant soil loss from areas of pastoral hill country.

13. Afforestation was often seen as the most-efficient, environmentally sustainable, cost-effective, and preferred treatment option for areas where, if they remained untreated, there was a high risk of erosion worsening. In attempting to combat the erosion problem some 155,000 hectares of exotic forest has been planted.

14. With climate change predictions for the East Coast region of the North Island suggesting that extreme storm events will become more common, it is inevitable that there will be a need for additional areas of landslide-scarred pastoral hill country within the Tertiary terrain to be afforested. However, afforestation, including plantation forestry, can create other issues, and management of these is discussed further below.

Benefits of afforestation

15. Often understated are the net environmental benefits of exotic plantation forests during their growing cycle and their role in ameliorating erosion during large storm events. For example, once pine trees reach canopy closure, at around eight years old, they become effective at:

(a) retaining soil on the hills where it can continue to be used for productive purposes;[21]

(b) reducing the occurrence/density of shallow landsliding;[22]

(c) reducing rates of earthflow displacement;[23] and

(d) reducing the volume of sediment generated from gullies if less than 10 hectares in size.[24]

16. The reduction of sediment supply to stream channels results in:

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21 Marden, M; Phillips, C; Rowan, D (1991). Declining soil loss with increasing age of plantation forest in the Uawa catchment, East Coast Region, North Island, New Zealand. Proceedings of the International conference on sustainable land management, Napier, New Zealand, 358-361; and Marden, M. (2004). Future-proofing erosion-prone hill country against soil degradation during large storm events: have past lessons been heeded?' (Professional paper). New Zealand Journal of Forestry, 49 (3), 11-16.

22 Phillips, C; Marden, M; Pearce, A. (1990). Effectiveness of reforestation in prevention and control of landsliding during large cyclonic storms. Proceedings of 19th International union of forestry research organisations (IUFRO), Montreal, 341-350; and Marden, M, & Rowan, D. (1993): Protective value of vegetation on Tertiary terrain before and during Cyclone Bola, East Coast, North Island, New Zealand. New Zealand Journal of Forestry Science, 23(3), 255-263.

23 Zhang, X; Phillips, CJ; Marden, M. (1993). A comparison of earthflow movement rates on forested and grassed slopes, Raukumara Peninsula, North Island, New Zealand. Geomorphology, 6, 175-187; and Marden, M., Phillips, CJ., Rowan, D (2008) Recurrent displacement of a forested earthflow and implications for forest management, East Coast Region, New Zealand. Sediment Dynamics in Changing Environments (Proceedings of a symposium held in Christchurch, New Zealand, December 2008). IAHS Publ. 325, 2008. 491.

24 Marden, M.; Arnold, G.; Gomez, B.; Rowan, D. (2005). Pre-and post-reforestation gully development in Mangatu Forest, East Coast, North Island, New Zealand. River Research and Application Special Issue 21, 757-771; Marden M. (2012). Effectiveness of reforestation in erosion mitigation and implications for future sediment yields, East Coast catchments, New Zealand: A review. New Zealand Geographer, 68(1): 24 35. <Go to ISI>://WOS:000302226000003; Herzig A, Dymond J, Marden M. (2011). A gully-complex model for assessing gully stabilisation strategies. Geomorphology. http://doi:10.1016/j.geomorph.2011.06.012; and Marden, M., & Seymour, A. (2022). Effectiveness of vegetation mitigation strategies in the restoration of fluvial and fluvio-mass movement gully complexes over 60-years, East coast region, North Island, New Zealand. New Zealand Journal of Forestry Science 52:19. https://doi.org/10.33494/nzjfs522022x226x.

(a) improvements in water quality and in-stream habitat equivalent to that of streams draining indigenous forest;[25]

(b) previously aggrading stream channels starting to incise,[26] thereby alleviating the risk of future flooding and sediment deposition on floodplains;

(c) reduced rate of sediment yield delivered to larger rivers and then to the coastal ecosystem;[27] and

(d) reduced need for expensive channel excavation, realignment and/or the construction of stop banks.

Sustainability of production forestry in fragile "high risk", erosion-prone landscapes

17. Tertiary sediments on steep slopes are very prone to landslides and debris flows. When saturated, the thin mantle of ash slips off the underlying impermeable bedrock. This is especially after ongoing heavy rain and post-harvesting. Research has shown a 'window of vulnerability' post-harvest that extends until the new crop develops a closed canopy and sufficient root mass to prevent landsliding.

18. These geomorphological processes are the same as those that have shaped the landscapes within Tairāwhiti since before human occupation.[28] However, rainfall intensities/totals during ex-tropical Cyclones Debbie and Cook (April 2017), ex-Cyclone Hale (January 2023) and Cyclone Gabrielle (February 2023) have exacerbated on-site landslide damage to both pasture, exotic, and indigenous forest, including delivering large quantities of woody debris and sediment to river channels and to downstream-receiving environments, such as beaches or river floodplains.

19. Therefore, within the Tertiary terrain, paramount to the sustainability of production forestry, and any alternative land use options, are the:

(a) prevention of the further loss of the coverbed materials (soil, volcanic ash, colluvium) overlying impenetrable bedrock; and

(b) preservation of these materials where they remain intact.

20. Production forestry on steep slopes with thin soil raises the following challenges:

(a) Shorter rotation species, like radiata pine, open the land to renewed slipping during the window of vulnerability approximately every 28 years after they are harvested. The area affected by landslides increases over multiple rotations

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25 Parkyn, S., Davies-Colley, R., Scarsbrook, M., Halliday, J., Nagels, J, Marden, M., Rowan, D. (2006). Pine afforestation and stream health: a comparison of land-use in two soft rock catchments, East Cape, New Zealand. New Zealand Natural Sciences 31, 113-135.

26 Peacock, D.H., Marden, M. (2019). Mean bed level trends in the upper Waipaoa river channel and Te Weraroa stream in response to land use change: 1948 to 2019. Prepared for Gisborne District Council.

27 Herzig A, Dymond J, Marden M. (2011). A gully-complex model for assessing gully stabilisation strategies. Geomorphology. http://doi:10.1016/j.geomorph.2011.06.012; and Marden M. (2012). Effectiveness of reforestation in erosion mitigation and implications for future sediment yields, East Coast catchments, New Zealand: A review. New Zealand Geographer, 68(1): 24 35. <Go to ISI>://WOS:000302226000003.

28 Marden, M., Basher, L., Phillips, C., Black, R., (2015). Should detailed terrain stability or erosion susceptibility mapping be mandatory in erodible steep lands? New Zealand Journal of Forestry, 59(4), 32–42.

because the rate of soil development is slower than the rate at which new landslides occur during the period of vulnerability between successive tree crops. compared to the additional slips between successive tree crops. This leads to a reduction in the productive capacity of the land. The soil is slow to develop because the mudstone, sandstone or siltstone rock needs time to weather into soil.

(b) Areas in slips become gaps in the re-established plantation. Gaps are natural funnels for the wind. Trees on thin soils have shallow root mats making them more susceptible to wind toppling. Windthrown trees open the soil for direct rainwater entry, which can also compound slipping.

(c) The process of harvesting, especially ridge-to-ridge logging can create soil disturbance, depending on the harvest method and the site's terrain. Dragging logs down opposing logging faces sweeps both slash and soil downhill. Exposed soil is more prone to sheet-wash erosion, which may compound soil loss.

21. The challenge ahead for plantation forestry is better understanding the cause and effect relationships following forest removal on slopes considered to be susceptible to the initiation of shallow landslides. Equally important is the influence of planting density regimes and silvicultural practices in altering the hydrology and mechanical reinforcement properties during the post-harvest replanting period.[29]

Land assessment

22. The best way to address long-term sustainability of plantation forestry on Tertiary terrain is by assessing the individual site's features. This includes assessing the site's susceptibility to landslides and its potential uses.

23. Both the Erosion Susceptibility Classification (**ESC**) and Resource Management (National Environmental Standards for Plantation Forestry) Regulations 2017 (**NES-PF**) provide a coarse screening tool with which to assess landslide 'risk' and further improve risk analysis at a forest operational scale. However, there are no current site-specific erosion models. This is problematic, as there are a wide variety of erosion processes operating within Tairāwhiti where the activity of different types of erosion and their potential to deliver sediment and slash to streams is strongly influenced by factors evident only at a more localised scale including:

(a) geology (structure (dip and strike of strata), composition (ratio of sandstone to mudstone, frequency of bedding), and intactness (degree of disruption to strata) of sedimentary lithologies);

(b) geomorphology (intensity of stream dissection and depth of incision, slope steepness, length and shape (concave vs convex));

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[29] Marden, M., & Seymour, A. (2022). Effectiveness of vegetation mitigation strategies in the restoration of fluvial and fluvio-mass movement gully complexes over 60-years, East coast region, North Island, New Zealand. New Zealand Journal of Forestry Science 52:19. https://doi.org/10.33494/nzjfs522022x226x

(c) composition (soil, volcanic ash, colluvium), and thickness of coverbed materials; and

(d) subsurface drainage pathways (bedding planes, tunnel gullies, old root channels, fault crush zones).

24. A better understanding of the role that these site-specific factors play in contributing to erosion and slope failure, both during the growth phase of production exotic forests, and more so during the post-harvest period, would require a fit-for-purpose landslide susceptibility methodology and an improved understanding of the magnitude and frequency of triggering events.

25. Additionally, the adoption of risk-assessment tools and morphometric connectivity models (which predict sediment and slash pathways and potential connectivity to channels) will become critical for underpinning management strategies and policies aimed at mitigating storm-related mass movement and sediment production, particularly following harvesting.[30]

26. A risk assessment should include an evaluation of likely downstream impacts. The information provided would greatly help decisions regarding the future of forestry on these sites, and/or in deciding potential post-harvest land use options that may be more suited to providing long term sustainability and as a pathway to establishing a permanent forest cover.

27. The adoption of such models is critical for identifying:

(a) potential sites for future afforestation, and preferred species choice;

(b) the factors that predispose forested areas to repeat episodes of predominantly storm-initiated erosion;

(c) the likely connectivity between landslide erosion and waterways for areas identified as 'moderate' to 'very high' landslide susceptibility with the potential to result in adverse consequences;

(d) land classes with potential ongoing economic value from the production of timber and where future harvesting is unlikely to jeopardise the initial erosion-control function of the forest or contribute to adverse offsite impacts;

(e) high-risk areas with potential economic value over a longer time frame, and where timber extraction would be possible, while maintaining a near-continuous

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[30] Spiekermann, R.I., & Marden, M (2018). Best options for land use following radiata harvest in the Gisborne District under climate change: Spatial analysis of erosion susceptibility in plantation forests, East Coast Region. MPI Technical Paper No: 2018/47; Spiekermann, R.I., Smith, H.G., McColl, S., Burkitt, L., Fuller, I.C. (2022). Development of a morphometric connectivity model to mitigate sediment derived from storm-driven shallow landslides. Ecological Engineering, 180, 106676. https://doi.org/10.1016/j.ecoleng.2022.106676; Basher, L., Harrison, D., Phillips, C., Marden, M., (2015). What do we need for a risk management approach to steepland plantation forests in erodible terrain. N. Z. J. For. 60 (2), 7–10; Marden, M., Basher, L., Phillips, C., Black, R., (2015). Should detailed terrain stability or erosion susceptibility mapping be mandatory in erodible steep lands? New Zealand Journal of Forestry, 59(4), 32–42; Phillips, C., Marden, M., Basher, L., 2012. Plantation forest harvesting and landscape response - what we know and what we need to know. N. Z. J. For. 56 (4), 4–12; and Payn, T., Phillips, C., Basher, L., Baillie, B., Garrett, L., Harrison, D., Heaphy, M., Marden, M., 2015. Improving management of post-harvest risks in steepland lantations. N. Z. J. For. 60 (2), 3–6.

canopy cover, and unlikely to jeopardise the initial erosion-control function of the forest or contribute to adverse off-site impacts; and

(f) very high-risk areas justifiably designated for retirement and reversion to a permanent forest cover to provide longer-term mitigation against the initiation of shallow landslides, and further reduce sediment delivery to streams.[31]

28. Similarly to current erosion modelling, the current Land Use Capability (**LUC**), geology, and soil mapping are at a broad scale (often at 1:250 000 or 1:50 000), so although helpful, they are not at the scale to make complex economic land use decisions. A suitable forestry scale is 1:5 000 or 1:10 000. An alternative is to use geomorphology specialists, or those trained in LUC mapping, to create these maps using LiDAR coverage for slope, and aerial imagery and field inspections for field validation.

Alternative management options

29. Once site assessment has occurred, the adoption of alternative management options for areas identified as high risk to landslide initiation will be paramount in alleviating the risk of slope failure and resultant soil loss. For example:

(a) planting high-value timber species with a longer rotation length; and/or

(b) planting coppicing species.

30. Areas considered very high risk and unsuited to any form of harvesting will need to transition to a permanent indigenous forest cover. The risk of leaving existing exotic forests standing as a permanent carbon forest in very-high-risk areas is likely to produce an even greater volume of slash over a considerably longer time as forest stands deteriorate with age due to windthrow and stem snap.

31. Change will, however, have implications for the financial viability of many of the exotic forests located in the Tairāwhiti region.[32] Addressing issues of sustainability will, in the longer term, lead to significant areas of high-risk production forestry land transitioning to appropriate forestry method that account for scale, intensity and risk, including to a permanent forest cover.

32. Consequently, there is a need for:

(a) improved models and tools for identifying areas of high risk to the initiation of landslides and their connectivity to stream channels during all stages of a rotation, but particularly after harvest.

(b) more site-specific scientific, third-party research to improve understanding of the afforestation choices for specific sites in Tairāwhiti.

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[31] Marden, M., & Seymour, A. (2022). Effectiveness of vegetation mitigation strategies in the restoration of fluvial and fluvio-mass movement gully complexes over 60-years, East coast region, North Island, New Zealand. New Zealand Journal of Forestry Science 52:19. https://doi.org/10.33494/nzjfs522022x226x.

[32] Lambie, SM., Awatere, S., Daigneault, A., Kirschbaum, MUF., Marden, M., Soliman, T., Spiekermann, RI., Walsh, PJ. (2021). Trade-offs between environmental and economic factors in conversion from exotic pine production to natural regeneration on erosion prone land. New Zealand Journal of Forestry Science. 51:14. https://doi.org/10.33494/nzjfs512021x163x

Streamside management zones (SMZs) and intercepting sediment and slash

33. A 'streamside management zone' (**SMZ**), or riparian strip/area, is a forest margin next to a waterway. A SMZ can trap non-concentrated overland flow originating from recently harvested areas that has been mobilised by storm water as it passes through. It does so by providing 'roughness' that effectively reduces the velocity of water so the sediment settles out (e.g by roots, needles, or leaves) or is trapped by the soil in the humus layer. The SMZ will filter out much of the mobilised sediment prior to it reaching the waterway. However, any concentrated flows, where water has accumulated and increased in velocity, are very likely to pass through the SMZ. Concentrated flows should be avoided as part of good harvest practice, e.g. using cut-outs on skid trails, frequent water discharge onto the cutover from infrastructure. SMZs both minimise the delivery of sediment into the waterway during harvesting, thereby maintaining water quality, and preserve the aquatic ecosystem.[33]

34. SMZs can vary in width. As an example, a typical width in North America is 50 feet (15m), and some States will increase the length of their SMZs according to slope. SMZs are most commonly not exclusion zones, and, as such, will differ by region in terms of width; required vegetation; canopy cover; and restriction with regard to harvesting practice, such as tree removal or equipment entry. Such an approach was promoted in New Zealand by Visser and Fenton.[34]

35. While SMZs are specifically mentioned in New Zealand best practice guide documents, such as the New Zealand Forest Owners' Association Environmental Code of Practice (**ECoP**), there is no mandatory use of SMZs associated with harvesting in New Zealand, and even limited guidance on when they should be used as sediment buffers. The recently published (December 2022) Eastland Wood Council "Good Practice Guide for Catchment Management" also specifically calls for the use of streamside protection zones to minimise the mobilisation of slash, and recognises the effectiveness of leaving mature trees as live slash traps.

The challenges of converting pine forests to indigenous forests

36. Although not directly within the three experts' field of expertise, Brett Gilmore and Mike Marden have worked with forestry managers over the last three decades which has informed them about the challenges of converting pine forests to indigenous forests. There are two paths to indigenous forest reversion, passive and active land change.

Passive reversion

37. In New Zealand, passive reversion follows two main forest compositional pathways, either mānuka/kānuka shrubland or broadleaved species.[35] Successful recolonisation of forest

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[33] Quinn J 2005. Effects of rural land use (especially forestry) and riparian management on stream habitat. New Zealand Journal of Forestry February 2005: 16–19.

[34] Visser, R. and Fenton, T. 1994. Developing Streamside Management Guidelines for New Zealand Production Forestry. Liro Report. Vol. 19. No. 7. Liro Forestry Solutions. Rotorua, NZ: 16.

[35] Williams, P.A. (1983). Secondary vegetation succession on the Port Hills, Banks Peninsula, Canterbury, New Zealand. New Zealand Journal of Ecology, 21, 237-247. https://doi.org/10.1080/0028825X.1983.10428556; Wilson HD (1994). Regeneration of native forest on Hinewai Reserve, Banks Peninsula. New Zealand Journal of Ecology 32(3): 373-383; and Smale MC, Kimberley MO (1994).

cutover is largely determined by the presence of a residual seed source in the soil, the availability of a seed source from a nearby and mature indigenous stand,[36] wind and a resident bird population.[37]

38. The challenge with passive conversion of pine forest to indigenous forest is about seed source, pest control, and the site's physical features. The latter includes aspect, slope, climate, rainfall and consistency of rain, soil moisture retention, and maximum temperatures and effects of equinox gales.

39. Weed competition and wilding pines are major factors inhibiting indigenous forest regeneration.[38] Costs for herbicide range between $300 and $500 per hectare.[39] A range of approaches have been used with various levels of success. Most strategies have involved different combinations, strengths, methods, and timing of herbicide applications to control weeds.[40] Whereas spraying to desiccate wilding exotics limits the diversity and density of indigenous species that germinate (thereby delaying the reversion process by several years), not spraying will result in a major, long term, wilding management problem, though it will produce a denser vegetation cover more quickly.

40. For example, Forest Lifeforce's 4,000-hectare Maungataniwha Pine Forest conversion is the largest in New Zealand. Since around 2012, the Trust has been working hard to make the conversion to indigenous species. The site is excellent to convert because of its abundant seed source due to it being beside a large indigenous tract. Additionally, the site is on easy to moderately steep terrain, with good soil and moisture retention. However, conversion still requires significant investment of time and resources. The major challenge, and cost, is eliminating regenerating pine seedlings, which crowd out the slower-growing indigenous forest species. At Maugataniwha, it will take ten years to progress to indigenous vegetation and remove the last of the regenerating pines.

41. Sustained browsing by feral and domestic animals also has a significant effect on both the composition and density of the groundcover species, particularly the more palatable broadleaf species, delaying the effectiveness of root reinforcement and canopy closure in

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Regeneration patterns in montane conifer/broadleaved forest on Mt Pureora, New Zealand. New Zealand Journal of Forestry Science 23(3): 123-141.

[36] Moles AT, Drake DR (1999). Potential contributions of the seed rain and seed bank to regeneration of native forest under plantation pine in New Zealand. New Zealand Journal of Botany 37: 83-93; and Overdyck, E., Clarkson, B.D. (2012). Seed rain and soil seed banks limit native regeneration within urban forest restoration plantings in Hamilton City, New Zealand. New Zealand Journal of Ecology, 36, 177-190.

[37] Enright NJ, Cameron EK (1988). The soil seed bank of a kauri (Agathis australis) forest remnant near Auckland, New Zealand. New Zealand Journal of Botany 26(2): 223-236; and Kelly D, Sullivan JJ. (2010). Life histories, dispersal, invasions, and global change: progress and prospects in New Zealand ecology, 1989–2029. New Zealand Journal of Ecology 24(1): 207-217.

[38] Marden, M., Lambie, S., & Phillips, C. (2020). Potential effectiveness of low-density plantings of mānuka (Leptospermum scoparium) as an erosion mitigation strategy in steeplands, northern Hawke's Bay, New Zealand. New Zealand Journal of Forestry Science, 50:10. https://doi.org/10.33494/nzjfs502020x82x; and Marlborough District Council, Department of Conservation, Marlborough Sounds Restoration Trust. (2016). Guidelines for converting pine plantations to native vegetation in the Marlborough Sounds: 11.

[39] Shaw P (2019). Annual Report 2018-2019 prepared for Lifeforce Forest Restoration Trust: 76; Marlborough District Council, Department of Conservation, Marlborough Sounds Restoration Trust. (2016). Guidelines for converting pine plantations to native vegetation in the Marlborough Sounds: 11; and Forest Lifeforce Restoration Trust (2019). Battle of the pines. Retrieved 16 January 2019, from, updated 22 August 2019: https://www.forestlifeforce.org.nz/post/battle-of-the-pines.

[40] Marden, M., Lambie, S., & Phillips, C. (2020). Potential effectiveness of low-density plantings of mānuka (Leptospermum scoparium) as an erosion mitigation strategy in steeplands, northern Hawke's Bay, New Zealand. New Zealand Journal of Forestry Science, 50:10; and Marlborough District Council, Department of Conservation, Marlborough Sounds Restoration Trust. (2016). Guidelines for converting pine plantations to native vegetation in the Marlborough Sounds: 11.

re-establishing slope stability.[41] Goats are a significant problem in Tairāwhiti. Goats are widespread, prolific (in their hundreds or thousands) and rapidly become human shy after culling. They can strip the undergrowth to nothing. Also, the terrain is both remote and challenging to access.

42. Depending on the site, the challenges of conversion to indigenous forest could be significantly harder for the Tairāwhiti region than in other areas. The natural regeneration is not as diverse or as rapid, due to the lack of remnant seed sources, and introduced weed pests, including regenerating pine.

43. Another challenge Tairāwhiti faces is that some of the existing tree crop may not be harvestable. That could be seen as a mixed blessing as the existing trees, if progressively thinned or poisoned, act as a cover crop for indigenous growth below. However, the existing pines add to management complexity, including animal pest control. The reality is that managing the succession of pine to indigenous species is expensive, time-consuming, and likely labour-intensive.

Active reversion

44. Active reversion is planting indigenous species. This is expensive and has many challenges including site mortality, and plant and animal competition that can easily lead to low survival rates. Based on plot growth trials of some of the more common early colonising indigenous plant species known to recolonise pine cutover, the planting of equal numbers of the best performing of the trialled species at 1100 ha-1 would mitigate surface erosion processes (rain splash, slope wash and minor rilling) within 2 years of establishment. Within 5 years, planting would likely provide only minimal protection against the initiation of shallow landslides. Assuming that the initial planting density is maintained (i.e. survival of ≥ 90% of establishment plantings), the expectation is that a moderate level of protection would occur by year 8 but the prevention of the initiation of shallow landslides during extreme storm events is unlikely. Stands at this density are unlikely to provide a high level of protection until year 16.[42] At higher densities (e.g., 2000 stems ha−1), as long as survival rates are ≥ 90% of establishment plantings, the likelihood of a successful erosion control outcome increases with increasing age and maturity of the plantings.

45. While the New Zealand Government has implemented a wilding pine control programme, and included provision for wilding pine control in the NES-PF, these strategies do not necessarily apply when converting pines to indigenous forests.

46. Additionally, the success or failure of either passive or active management may depend on the recurrence interval and magnitude of future storm events.

[41] Wallis, F.P. (1966). Report on a survey of the condition of the forests, scrubland, and grasslands of the upper Ngaruroro Catchment. Protection Forestry Report, 24. Protection Forestry Branch, Forest Research Institute, Forest and Range Experimental Station, Napier: 103; and James, I.L. (1969). Report on a reconnaissance survey of the protection forest land in the Poverty Bay-East Cape District. Protection Forestry Report, 50. Protection Forestry Branch, Forest Research Institute, Forest and Range Experiment Station, Napier: 23.

[42] Marden, M., Lambie, S., & Phillips, C. (2020). Potential effectiveness of low-density plantings of mānuka (Leptospermum scoparium) as an erosion mitigation strategy in steeplands, northern Hawke's Bay, New Zealand. New Zealand Journal of Forestry Science, 50:10. https://doi.org/10.33494/nzjfs502020x82x.

47. Consequently, more site-specific scientific, third party research is required to improve our understanding of converting pines to indigenous forests on the challenging geology/soils of Tairāwhiti.

Harvesting before retiring to indigenous forest

48. There are differing views on the best way to return land to indigenous forest from pines. This is not any of our areas of expertise, but we note the following views.

49. For most sites intended to be retired from production forestry, it makes sense to first harvest the existing crop. This will help avoid mobilisation of the mature forest should mass movement occur on what has been identified as an at-risk area. In particular, leaving tall, wind-exposed pine, with shallow root balls, to naturally regenerate is highly risky in steep tertiary terrain.

The numerous windthrown trees, as evidenced by their attached root balls, show the challenges of leaving pines as a nurse crop for indigenous species on skeletal soils.

A challenging situation where a slip down into the waterway has taken down mature trees. Most likely this area will be retired from subsequent rotations. Retrieving these trees will be challenging and potentially dangerous at time of harvest.

50. However, there will be site specific areas that may be best left unharvested. This likely includes streamside management areas with steeply incised gullies, where the stand provides stability, and the ability to both trap mobilised sediment and woody debris.

Effectiveness of well-constructed infrastructure

51. Improved construction starts with a good layout and design. Operational construction standards and regular supervision help ensure foundation work and associated fills are stable through engineering principles like clearing, stripping, and appropriate compaction. Better constructed infrastructure is more resilient to the effects of storms.

52. Aratu has significantly improved the company's infrastructure construction practices between 2018 and 2023. Infrastructure covers roads, landings, waterway crossings, and associated erosion and sedimentation control structures. This level of improvement has been funded by Aratu. For example, road construction costs have about tripled. The increased investment has resulted in improved construction standards.

53. Practices continue to improve in learning from previous impacts. After the cyclones culminating in the Labour Weekend 2018 storms, Aratu assessed about 760 previously constructed landings and their roading network to develop a rehabilitation plan. Approximately 20% of the landings required machinery to go back onsite to improve the quality of the existing post-harvest rehabilitation. This included pulling additional slash back onto the skid, end hauling slash to a more stable and contained site and improved water controls.

54. Aratu has also introduced the following improved construction methods:

(a) Benching all works where fill needs containing and compaction.

(b) Compaction to consolidate fill to a more stable and stronger state.

(c) Reducing fill slope angle (previously beyond the natural angle of repose).

(d) Less side cast and more cut and fill construction. Side cast uses the fill for construction without a bench.

(e) Increased end hauling to remove additional fill to a more stable and contained site.

(f) Vegetation stabilisation of fills to reduce sheet wash erosion like rilling.

(g) Increased water controls like crossroad drains and flexiflumes to reduce water volume and speed and help protect sensitive fill slopes.

(h) Improved erosion and sedimentation structures to reduce erosion and trap larger sediment.

55. Based on discussions with staff and from aerial observations, the recently constructed infrastructure held up better in the 2023 storms than earlier construction. This was evident in reduced landslides triggered by landing and road fill failures, and water control failures,

such as successive blocked culvert inlets. When road fill slopes are constructed steeper than what the soil can contain when saturated, these fills can initiate landslides immediately below roads and tracks. However, in areas where the soil is obviously very weak and the slopes steep, there were still a larger number of slumps and slides that originated either from or onto the infrastructure. It does indicate that once the soil is very saturated in these areas it can fail easily. Apart from maintaining the highest possible construction standards, the only other realistic step is to minimise the footprint of the disturbance to the greatest extent that still allows for safe passage for truck traffic.

Pre-Labour weekend road and landing construction with many infrastructure triggered landslides evident, including from road and landing fill slopes

Post-Labour Weekend infrastructure construction. It was evident this held up well.

56. Newly constructed infrastructure is likely more susceptible to erosion and mass earth movement from storm events. Well-constructed roads will bed down over time, effectively continuing to compact, and, more importantly, the cut-banks will stabilise and revegetate, reducing runoff related movement. In the future, you would expect even less storm damage from a similar intensity storm event. Some level of slumping and slips after storm events will always be an unavoidable characteristic of this region.

Infrastructure in the foreground has held up with minimal damage. However in the background there are many slumps / slips either onto the road or from the road (black arrows).

An example of a new-build landing that was in use by a cable yarding crew. Despite high construction standards and a relatively small footprint for such a large operation, there is still a slump right below the landing, a slip from the bench track on the left, and a slip most probably from the drainage as the road approaches the landing on the right.

Common misconceptions about 'slash'

57. Public perception is that all woody debris is from plantation forestry. This is seldom the case and, depending on the catchment and the other contributing wood sources, the contribution of plantation species to woody debris can be low. For example, in 2015, the Hawkes Bay Forestry Group, a regional forest sector lobby group, commissioned an independent report on the composition of woody debris washed up on Opoutama and Taylor's Bay, Mahia, after a heavy storm. The two different results reflect the different debris sources and coastal currents. The results are seen below:

RESULTS FOR TAYLOR'S BAY

COMBINED DATA (3 X 200 m^2 Plots) for TAYLOR'S BAY

	150-300 mm	301-450 mm	>450 mm	Total	
Pines	26	42	5	73	33%
Poplar/Willow	10	36	19	65	29%
Others	6	44	36	86	38%
	42	122	60	224	

RESULTS FOR OPOUTAMA BEACH

COMBINED DATA (2 X 800 m^2 plots) for OPOUTAMA

	150-300 mm	301-450 mm	>450 mm	Total	
Pines	10	16	4	30	67%
Poplar/Willow	2	4	0	6	13%
Others	2	5	2	9	20%
	14	25	6	45	

58. The composition of woody debris likely reflects the composition of the species in the catchment that can mobilise through waterway bank collapse, landslides, debris flows or by direct entry to the water. For example, poplars and willows are extensively planted or subsidised by regional councils to assist in stream bank stabilisation, so it is not surprising in these catchments during storm flows that a large component of the slash would be these species. Likewise, in catchments with recently harvested pine plantations, pine would comprise the major slash species.

59. There are different ways to measure the composition of large woody debris. There are two guidelines currently used to assess Cyclones Hale and Gabrielle' woody debris in Tairāwhiti. The forestry sector uses Interpine Innovation's 3rd March 2023 'Woody Debris Assessment'. The other guide is Gisborne District Council's (**GDC**) 2023 V2.1 'Large Woody Debris Assessment Guide' used by the GDC.

60. However, to the extent that slash contributes to woody debris, the matters addressed below will assist in reducing slash.

Why a standard operating procedure or slash best practice guide would be effective

61. The most significant environmental risk in the plantation forestry cycle is at harvest. Mobilised slash creates the largest impact, mainly when it migrates from the forest and affects neighbours and the community's safety, access, property, environment, and recreational opportunities.

62. The NES-PF does identify the need to manage slash, and there are four New Zealand Forest Owners' Association Best Practice Guides (**NZFOA BPG**) that address slash (6.1 managing slash on landings; 6.2 managing slash on high-risk cutovers; 6.3 managing slash around waterways; and 6.4 use of slash traps).[43] Also, the SafeTree website provides a standard slash management template for companies to use.[44] However, while these documents provide basic guidance, considerable effort can be made to provide more detailed and specific guidance as to best practice, which will encourage improved and more consistent practices.

63. A standard operating procedure (**SOP**) for slash, in conjunction with other company guidance, like a company policy, should help businesses improve managing their slash risks. An SOP incorporates company policies and procedures into operational management so that those doing the work 'walk the talk'.

64. A national slash management best practice guide (**national slash BPG**) with minimum standards should help improve those who consider slash management a 'mop up' exercise and enhance knowledge and awareness around best slash practices. Risk identification and management may range from simple checklists to complex onsite and off-site effects modelling, leading to targeted site-specific slash approaches. A SOP or national slash BPG would address:

    (a) identifying slash and its causes;

    (b) clarifying the regulations around slash management (NES-PF and resource consents);

    (c) tools to help decide the level of slash risk, both on and off-site;

    (d) how managing slash at the landing helps prevent and reduce the problem, which requires pre-operational, during operations, and post-operational slash management;

    (e) managing slash on high-risk cutovers, including preventative actions, slash management plans, and operational methods that can assist in reducing slash volumes; and

    (f) managing slash near or in water, including determining acceptable slash loadings and potential slash movement risks.

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43 Forestry Owners' Association Forest Practice Guide, 2020 https://docs.nzfoa.org.nz/forest-practice-guides/.

44 Safetree Slash management plan https://safetree.nz/resources/slash-management-plan/.

Commissioning an independent science-based approach to catchment management

65. At the larger 'catchment management' scale the overall health of the catchment could be managed, e.g. water yield and quality, and pollution risks such as nitrate and sediment loading. There are only a few examples of this being implemented in New Zealand.

66. The challenge with individual NES-PF approvals and resource consents is that they are viewed as discrete packets. If different companies within a single catchment all file applications at a similar time because of concurrent planting, major issues could potentially arise. The difficulty of not taking a catchment-wide approach is that the overall effect of multiple parties logging at a parallel timeframe is not considered. This can significantly impact critical catchment-level environmental factors like water yield and the impact of erosion and sedimentation.

67. New Zealand research is slim on the appropriate percentage of a catchment that should be harvested over an acceptable time frame. There are New Zealand precedents and overseas research to assist in helping researchers decide if a catchment approach is suitable and what the level of environmental gains could be if such management were introduced. Some companies have used 25% or 50%, but by the nature of these numbers, they are more self-imposed rules rather than science-based outcomes.

68. Whatever the science decides on the best catchment clearance guidance, there are undoubtedly benefits of managing land use at a catchment level across all primary industries for many reasons. These include water yield and quality, nitrate and e.coli and other non-visual factors, sediment levels, and riparian and woody debris management.

69. At the smaller in-forest catchment scale, the forest manager can proactively manage aspects like setting well-informed planting boundaries and managing the extent and intensity of harvesting. This is consistent with implementing best practice guidelines.

Effectiveness of coupe harvesting limits, with green up requirements

70. Clear-cutting, also known as clearfelling, is a forestry/logging practice in which most, or all, trees in an area are uniformly cut down. It is a commonly accepted harvesting practice, with most certification schemes accepting it.

71. The issue with clearcutting is the scale at which it is implemented. Clearcutting larger catchment areas changes the hydrological response to rainfall events.[45] Many studies in forested catchments have shown that clearfelling a larger portion of the catchment will increase the hydrological response from a rainfall event.[46]

72. Coupe harvesting is clearfell harvesting with a limit on the extent of the felling. To make coupe harvests not simply a series of continuous smaller harvests, green-up rules are

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[45] Bosch, J., Hewlett, J. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. Journal of Hydrology 55:3-23; and Davie, T., Fahey, B. 2005. Forestry and water yield - current knowledge and further work. NZ Journal of Forestry 49(4):3-8.

[46] Hornbeck, J.W., Martin, C.W. and Egar, C. 1997. Summary of water yield experiments at Hubbard Brook experimental forest'. Can. J. Forest Res., New Hampshire 27, 2043–2052; and Swank, W. T., Vose, J. M. and Elliott, K. J. 2001. 'Long-term hydrologic and water quality responses following commercial clearcutting of mixed hardwoods on a southern Appalachian catchment', For. Ecol. Manage. 143, 163–168.

applied to limit when adjoining coupes are harvested. Research cited in Sidle and Ochiai suggests that limiting coupe sizes and or partial harvesting are highly effective ways to reduce erosion susceptibility of forest lands.[47] A rule-of-thumb is that harvesting more than 25% of a catchment will show a significant change in erosion from a peak flood. This combined with the increased availability of harvest residues, and the movement of soil, combines to increase the risk of a debris flow.

73. The major benefit of coupe harvesting and green-up rules is that scale, intensity, and risk (**SIR**) are incorporated into harvest planning. SIR helps recognise that the level of harvesting risk is based on the size of the harvested area, how rapidly the harvesting occurs, and the risk that comes with the work. The concept of coupe harvesting limits is identified as one of the key strategies for minimising the risk of debris mobilisation in the Eastland Wood Council "Good Practice Guide for Catchment Management".

74. Developing generic coupe harvesting and green-up rules through regulations would likely be too coarse of an approach. Not all forests, or areas within a forest, have similar risks, even in similar landscape. It may be possible to separately assess the wider harvest area, including catchment limits, and the risk at a more refined scale like the harvest unit or area. For example, a smaller, higher-risk site may need a smaller coupe size than a larger, lower-risk location. Still, high-level rules and guidance could assist in helping to address many of the current issues associated with SIR.

75. There is limited to no New Zealand research on the environmental, social, and economic cost/benefits of different coupe sizes and green-up restrictions. There needs to be more scientific, third-party research to improve our understanding of broader catchment level constraints as well as assistance in developing practical and effective coupe size and green-up provisions.

Removing slash and what to do with it

76. As noted above, the word 'slash' can mean different things to different people, so it is important to have a clear definition. The NES-PF describes slash as: 'any tree waste left behind after plantation forestry activities'. However, we know that slash comes in different forms, which need different management.

77. Slash, in and of itself, is not bad. It is organic matter that creates topsoil. Slash contains most of the nutrients the tree had stored, so it helps maintain or improve soil quality when it breaks down. Slash helps protects soil from erosion and sediment by being a ground cover until the site is vegetated again. Also, some wood in waterways improves habitat by creating shade, cover, and food.

78. In essence, slash is good when it is:

(a) in the right place;

(b) in the right amount;

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[47] Roy C. Sidle and Hirotaka Ochiai. 2006. Landslides: processes, prediction and land use, American Geophysical Union. American Geophysical Union, Washington DC, 307.

(c) the right sort of slash; and

(d) unlikely to move.

This site has large volumes of slash left on the site. However, it is more of an aesthetic issue than a slash risk one because it is unlikely to move.

79. The challenge around slash, and what creates its social and environmental problems, is when it mobilises. It can mobilise due to things within and outside forestry companies' control.

80. If the harvest site has slash mobilisation risks from the landing, the slopes, or in/near waterways, then the slash needs to be carefully managed. The amount of slash left should be determined by environmental risk rather than solely economic drivers. The environmental and economic drivers are linked, but many companies do not consider the opportunity cost associated with an environmental incident. For example, a failure to conduct repairs on in-forest infrastructure, like waterway crossings, can lead to outside-forest damage, which can result in a reduction in the company’s social licence to operate, civil legal action, or repair costs.

81. Progressive companies that recognise the cost of large woody debris on risky cutovers and, or in/near waterways are now extracting all larger woody debris, down to 2m and 10cm in diameter from the cutover, and all ‘binwood’ pieces from the landings. The challenge of removing slash with no viable bin wood market options is what to do with it all. This is a major challenge, especially in the steep hill country with limited safe and contained long-term storage areas. Although any woody / biomass material can be used for fuel and other products, the main issue is the availability of a market for residues, which in turn will be governed by quantity and quality requirements for the intended purpose, as well as distance to market.

82. Even in regions with well-established biomass markets, only billet-wood (typically >80cm length, >10cm dia – but specifications vary) will be successfully extracted from the landing – rarely from the cut-over. For it to break-even or create a small return to the forest owner, quantities of residues need to be carefully managed at time of harvest (accumulated and kept free of soil contamination), and delivered to a market less than 25 kilometres away. Removal of harvest residues outside of these parameters are likely to incur a direct cost. If

cost is to be incurred, most companies will prefer to follow best practice guidelines and store the residue in a stable location onsite.

83. Another important consideration, acknowledged by the safety caveat in the NES-PF, is the health and safety of workers. Having workers remove harvest residues from gully, especially steep or incised gullies, can readily be considered a dangerous task. Sending machinery down into gully or waterways to remove harvest residues, while effective, can result in soil disturbance that destabilises the streambank, increasing the risk of bank collapse.

84. Future research and investment that supports making value from large, otherwise non-merchantable, woody debris will also reduce future mobilisation issues.

Effectiveness of barriers, debris traps, and debris nets

85. Barriers or debris traps have been used to prevent harvest residues from moving off-site. While Ballie reported that many New Zealand companies had a 'just leave it' approach to managing slash,[48] Froelich reports on using barriers to reduce logging slash once it gets in streams in Western Oregon.[49] The ECoP also discusses using debris traps downstream of areas where it is difficult to carry out slash removal.[50]

86. It is recognised that woody debris will mobilise in steep catchments during large storm events, and that this cannot be wholly avoided. As such, debris traps do provide a mechanism to trap larger woody material prior to it being discharged further down the catchment. Catching debris early also prevents it from scouring additional material from the stream banks as it moves its way down.

87. Good planning will place a debris trap in a location where it can be readily cleared post-storm, as required by the NZFOA BPG for slash.[51] The installation of any structure in or around waterways will typically require a Resource Consent although the NES-PF allows for the installation of debris traps without consent in catchments area less than 20 hectares. Culvert crossings are readily consented because they are common, have good design manuals, and councils are comfortable with issuing a Resource Consent for them to be installed. For example, culvert sizing based on flow rate requirements is well established in the NZ Forest Road Engineering Manual (2018). However, there is no such design principle for debris traps – there is no way to calculate an expected debris load from a storm event, and engineers will be looking to provide a definitive answer for a specific design problem.

88. Most debris traps installed in New Zealand have been of simple design. They typically use railway irons driven into the ground at regular spacing (approximately 2 metres) and are supported by a wire rope that is anchored into the embankments (either using deadmen or stumps). While such simple designs may work effectively for smaller catchments, they are

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48 Baillie, B. 1999. Management of Logging Slash in Streams of New Zealand – Results of a Survey. Project Report 85. Liro Forestry Solutions. Rotorua, NZ. 31.

49 Froehlich HA. 1971: Logging debris managing a problem. In JT Krygier and J D Hall (eds), Forest Land Uses and Stream Environment, A symposium, Oregon State University, Corvallis, 112-117.

50 New Zealand Forest Owners' Association Environmental Code of Practice, 2007.

51 Forestry Owners' Association Forest Practice Guide, 2020 https://docs.nzfoa.org.nz/forest-practice-guides/, 6.4.

at risk of failing in larger storms. Such a failure can result in a sudden discharge of all the material that had previously been caught.

An example of a simple railway iron/cable debris trap anchored by deadmen.

An example of a newly constructed trap using wooden posts. While also capable of trapping mobilised residues, its main design feature is to drive the residues from the main flow path onto the embankment where it can settle.

A well anchored debris net that has successful trapped a large volume of large woody debris The image is from a Hawkes Bay. The company have noted their effectiveness, with the trap catching debris in even smaller storm events.

89. Debris nets have been installed in effectively in parts of New Zealand, but are not yet common. These structures are designed to allow water to continue to pass and to be over topped and remain intact. In general, nets have the greatest potential, as the European-based design manual has standard installation procedures, and, as the net is technically constructed above the waterway, no modification to the waterway is required as such.

90. Additional information on design principles for debris traps and nets will support future installation practices and acceptability.

APPENDIX 4

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04.04.2023

COMMERCIAL IN CONFIDENCE – Summary - Geobrugg Slash/debris flow barriers

1. Development History

Geobrugg is an international engineering company who specialises in geohazard and impact solutions. Geobrugg has over 60 years' experience with over 350 employees in more than 50 counties. In the last 10 years Geobrugg have installed over 250 debris flow barriers in more than 25 countries. Debris flow barriers are also used to contain driftwood or slash. The term slash is referring to the wooden debris from forest harvesting which has unintendingly migrated down slope and into the water channel. The wooden debris is commonly called driftwood in the European market but it will be referred to as slash in this report.

Geobrugg debris flow barriers began development in 2005 and proved successful retention in the large field tests. The design load approach was developed together with the WSL (Swiss Federal Institute for Forest, Snow and Landscape Research, which is a government research body). The debris barriers are made of high-strength steel wire nets and are fully established as a certified European product (EAD No. 340020-00-0106). Slash barriers were originally tested in 2015 at a test site in Füssen, Germany. The 1:1 testing confirmed that standard debris flow barriers were able to satisfy the dynamic and static loads exerted by wooden material.

In extreme weather events it is likely that there is also a large amount of debris in the river flow, so it's important to understand and to design for both scenarios. Slash and debris flow barriers are also commonly used post bush fire to mitigate the hazards associated with highly erodible slopes covered in post fire debris.

In 2021 the WSL released the 'Practical guide for debris flow and hillslope debris flow protection nets' which outlines the design process and considerations developed by the combined Geobrugg WSL research and testing over the last two decades. This guide is now used worldwide for applying slash and debris flow barriers.

Slash barriers are not designed to mitigate poor forestry practice but are useful tool in managing any waste material which was not able to be controlled at the source.

Figure 1 - Slash barrier examples

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1.1 Slash Barriers

A slash barrier is a secondary protection measure to contain wood debris which makes it way into the river during flood events. Slash in general should not be in the water way but can migrate down slope due to the force of water. The slash material often causes bridges to clog and downstream damage. Bridge clogging leads to higher water levels, break out of the river from its bed and the subsequent flooding of neighboring infrastructure. The best practice is to contain the slash at an intended location and have a management plan for access and clearing. A slash barrier also needs to be able to withstand any debris load from upstream erosion and slope failures.

The effectiveness of a slash barrier is limited to the retention volume. To maximise retention volumes the location of the barrier should be on a straight section of river, with sufficient bank height at either side for anchoring. At the entrance to a gorge or narrow section is a good location due to the increased retention upstream. Where topography limits the retention volume, several barriers can be installed. If the retention volume is exceeded, the barriers have edge protection on the upper ropes and are designed to be over topped and remain intact. Selecting a location where bedrock is shallow allows for more efficient anchoring and minimises bank erosion. For sites with erodible banks, stabilisation and anchor length redundancy is recommended. An example of bank stabilisation using a high tensile mesh is shown below (figure 2), rip rap or concrete can also be used if readily available.

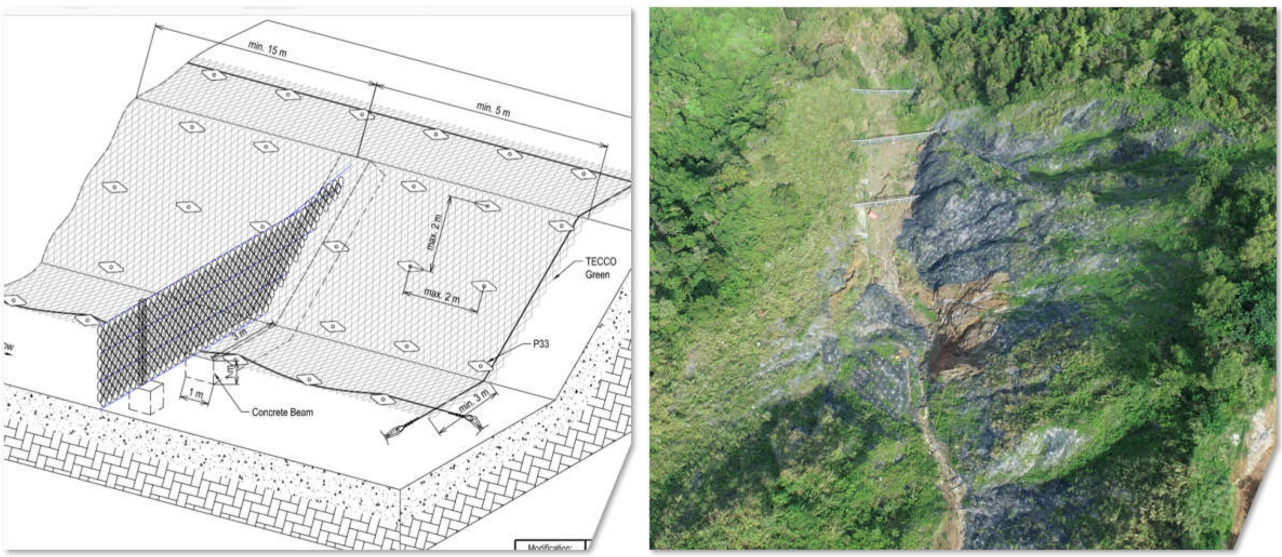

Figure 2 –Bank stabilisation using TECCO mesh in Carranglan - Philippines.

An advantage of the flexible Geobrugg slash barriers is their low weight and short installation time. This is important in steep, difficult terrain where access for large construction machinery is difficult and may cause damage to the environment. The high tensile net construction also has low visual impact (figure 3 and 4) and significantly less carbon pollution when compared to the concrete check dam. When the system is no longer required it can easily be removed and even re installed at a different location.

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Figure 3 - Three debris barriers systems installed in Switzerland with low visual impact

Figure 4 - VX 80 Shenandoah SH65 NZ with low visual impact

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1.2 Barrier Component Summary

Abrasion Protection – On top of each barrier along the support and winglet ropes an abrasion protection guard is installed to protect the upper support ropes during overtopping.

Ring nets – Flexible ring nets made out of high tensile strength steel have a high elastic/plastic energy absorbing capacity and are able to handle multiple impacts.

Winglets – At the top of every barrier a winglet extension rope concentrates the overtopping debris flow material to the middle of the barrier thus avoiding erosion of the torrent banks.

Brake elements – Plastically deforming brake ring elements reduce the peak loads in the ropes and absorb dynamic forces

Corrosion Protection – Geobrugg Supercoating (Zn-Al) and galvanization is provided on all components for long-life.

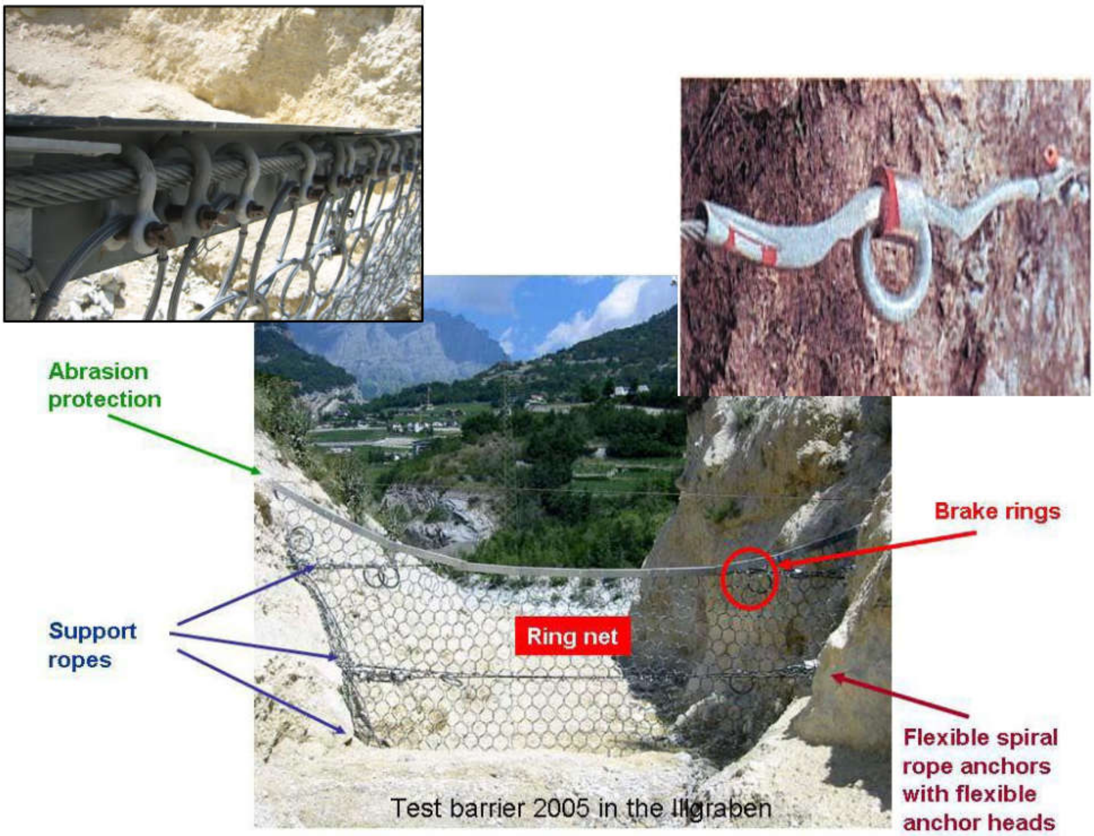

Figure 5 - Barrier components

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2. Local examples NZ

Five debris flow barriers have been installed in the last 5 years in New Zealand, with three more currently under construction. Geobrugg also had a significant role in the 2016 Kaikōura earthquake recovery with over 20 protection systems installed.
In 2021 the first dedicated slash barrier was installed in Napier in an 800Ha catchment. The barrier is a VX140 designed to withstand 140kN/m2. The system is 13.5m wide at the top, 8m wide at the bottom and 3.5m high. Wire rope anchors were used to transfer the loads back into the ground and provide design redundancy should some bank erosion occur. Edge protection was also installed on the top rope to protect the structure in the event of over topping.

Figure 6 - Slash barrier Napier

The slash barrier was first filled in March 2022 and successfully contained a combitantion of slash and landslide material. The system was then cleaned out and filled again in January 2023

Figure 7 - Left March 2022 filling. *Right - January 2023 filling*

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The barrier was cleared again in February 2023 and 2-3 days later was filled again. The barrier was over topped and remains intact (note due to road closures this barrier has only been inspected from the air)

The force exerted on the structure can be measured by measuring brake ring activation. After three loading events there is no elongation on the brakes which suggest the structure has not reached its maximum load.

After this successful install and real event testing, larger systems are planned.

Figure 8 - February 2023 filling

2.1 Proposed systems Aratu Forests

In 2019 Geobrugg were requested by Aratu Forests to provide a debris flow/driftwood barrier design for the Waimanu and Te Marunga sites. The following information was provided.

- System design of the debris flow/driftwood
- Proof calculations based on 1:1 field testing,
- Material specifications and anchor forces,
- Barrier design drawing,
- Declaration of Performance Certificates

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The custom system drawings follow:

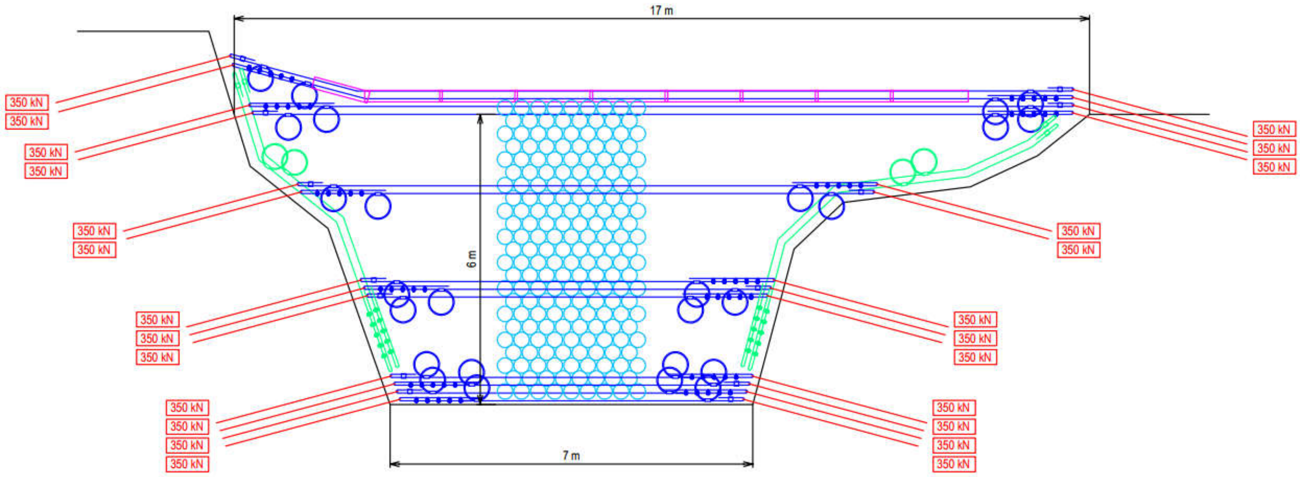

Figure 9 - Te Marunga rope assembly drawing

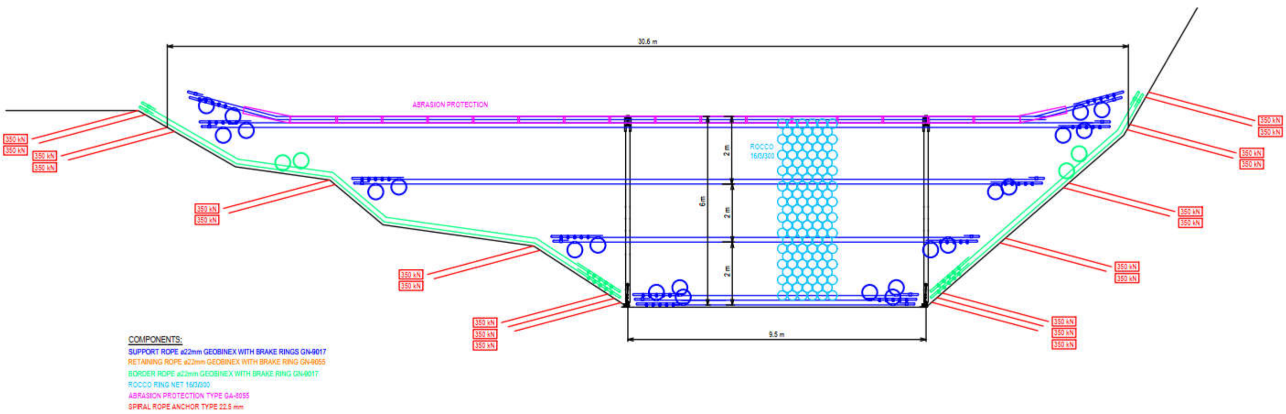

Figure 10 - Waimanu rope assembly drawing

Both systems were dimensioned to withstand a debris and slashing load including a dynamic puncturing load of a 15t tree stem traveling at 10m/s. The systems had edge protection to protect the top rope in the event they were over topped.

Geobrugg would recommend a design check with the latest data from the 2023 events prior to installing.

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3.0 International examples

As previously stated Geobrugg have installed over 250 debris flow barriers in more than 25 countries. The majority of these barriers are dominantly for debris flows. Structurally a debris flow barrier is the same as a slash barrier. Slash barriers should also be designed for debris loads as they have higher impact forces, given this, the following are all relevant design and test examples.

Sierra Nevada – VX Barrier
In August 2022 heavy rainfall post bush fire mobilised slashing material into the torrent.

Figure 11 - VX barrier in New Mexico

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Peru - UX barriers

To the east of Lima, Peru, El Niño rains caused multiple mudslides and landslides. In February 2016, Geobrugg installed 22 debris flow barriers to protect people and infrastructure in the nine valleys of the Chosica Region. A year after the installation the worst storms in the 30 years struck north of Peru.

The 22 barriers performed well. The below images show a 55 meters stretch, one of the 4 levels of the barrier system. Two of these barriers were filled to 95 percent capacity (10,000 m³ in retained material). The multilevel design increased the retention volume, meaning that there is still capacity in the downstream barriers. Most importantly the residential area below was protected.

Figure 12 - UX Barrier after construction.

Figure 13 - Same barrier filled

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Switzerland

Many systems have been installed in Switzerland. To demonstate Geobrugs capabilities a summary of the Hüpach barrier follows which is 40m wide and 10m high, the largest debris system in the world.

The barrier was planned and installed to protect a settlement below which was highly endangered by debris flow and flooding. The goal for the client, Geobrugg and the planner was to find a cost effective solution to save guard lives, buildings and property. The barrier has not yet been filled.

Key figures of the drainage basin:

- Retention capacity: 16´000 m³
- Average slope inclination in the flow channel: 32 %
- Length of the main channel: 4150 m
- The peak discharge for a return period of 300 years is 350 m³/s. Debris flow modelling was calculated using the software RAMMS from SLF / WSL (Switzerland).

Figure 14 - Hüpach System 40m wide 10m high

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Milibach Halisberg, Switzerland

In August 2005, a storm in the Weiler Reuti and in Meiringen caused serious debris coverage and severe damage. To protect the two settlements, a cascade comprised of 13 flexible debris flow barriers were installed to retain a cumulative volume of up to 10,000 m³.

On October 10, 2011, heavy rainfall triggered a shallow landslide containing a total of 2,000 m³ of schist into the drainage area of the Milibach river. Approximately 80mm of rain fell onto a 70 cm layer of existing snow in 12 hours. The Swiss Federal Office for Environment (FOEN) categorised these heavy rainfalls as the 100-year event.

The event filled barrier no. 2 completely and barrier no. 5 partially. Barrier 1, which was situated above where the shallow landslide was triggered and remained unaffected, while barriers 3 and 4 were not filled as they have a higher basal opening.

Stopping the 2,000 m³ of debris helped prevent further erosion along the unstable banks of the Milibach River and dissipated an event that could have caused damage to the settlements further downstream. After an in-depth investigation during an on-site inspection, the customer decided to leave barrier no. 2 filled to protect the riverbanks. The debris held by barrier no. 5 is also being left and should be carried away over time as the water drains naturally.


Figure 15 - Left VX Barrier. *Right - Filled VX barrier*

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Illgraben Switzerland

After countless debris flow events in the Illgraben, concrete check dam No. 25 was completely eroded on its right bank and the concrete flanking walls were bypassed by debris material. To sustainably secure the channel course two debris flow barriers were installed.

Figure 16 - Illgraben Debris flow barrier

The frequent debris flows in the Illgraben due to its highly erodable catchment up stream make it the perfect location for Geobrugg and the WSL to use as test site. Systems are installed in the channel and are tested with natural debris flows and performance analysed. The 1:1 test information helps correctly dimention systems for different flow heights, velocities and compositions.

Figure 17 - WSL and Geobrugg test site

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North America - News articles from California after deadly 2018 fire and mudslides

https://www.independent.com/2023/01/18/did-the-steel-curtains-help-montecito/
'Back in 2018 at the time of Montecito's deadly debris flow, none of the steel nets or the Randall Road basin were even being considered. Thus there was nothing stopping its lethal path on January 9, which killed 23 people, destroyed or damaged 500 structures, and blocked Highway 101 for weeks.
Pushing for the installation of the steel curtains was a group of civic-minded Montecito residents who formed the private nonprofit, the Partnership for Resilient Communities, which raised nearly $6 million to make their dreams of steel netted safety become a reality.'

Figure 18 - Image from news article of Geobrugg debris flow barrier

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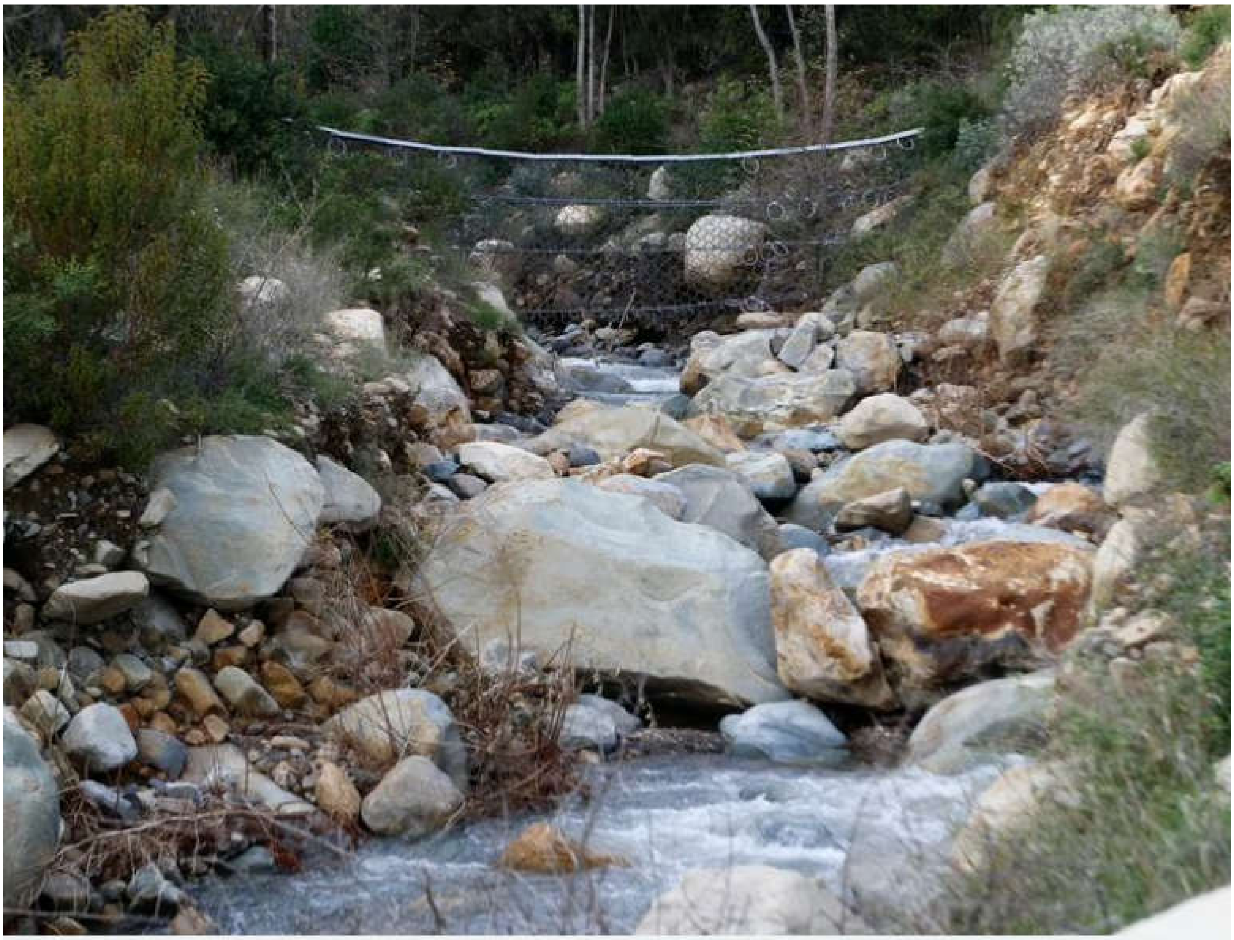
https://www.opb.org/article/2023/01/15/california-mudslides-defense-wet-weather-storms-damage/
'The best solution for the Montecito and Santa Barbara area is to have both nets and debris basins, according to Larry Gurrola, the engineering geologist hired by the organization.'



Netting made from mettle cables is visible above a creek in Montecito, Calif., on Jan. 12, 2023. With climate change predicted to produce more severe weather, officials are scrambling to put in basins, nets and improve predictions of where landslides might occur to keep homes and people safe.
Ty O'Neil / AP

Figure - 19 Image from news article of Geobrugg debris

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https://archive.vcstar.com/news/local/camarillo/project-in-camarillo-springs-builds-barriers-26f61ca4-dfc3-1195-e053-0100007f9ff4-362831161.html
KANE GeoTech worked with Geobrugg AG, a Swiss company that manufactures the barriers, which Kane said were "the best products out here, especially for debris flow."
Kane said that Geobrugg has spent millions of euros developing and engineering the debris flow barriers "so you can be pretty confident that they're going to work and perform well."

Project in Camarillo Springs builds barriers

ANTHONY PLASCENCIA/THE STAR Camarillo city officials tour a hillside in the Camarillo Springs area where a debris flow control system is being construction in culverts where heavy rains caused a massive mud flow late last year.

Figure 20 - Image from news article of Geobrugg debris

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4.0 Conclusions

Geobrugg are the pioneers and the most experienced with Debris and Slash barriers. If the barrier is dimensioned correctly and installed in a suitable location, they are an extremely useful tool to protect downstream assets.

Geobrugg work with industry leading consultants and contractors to ensure the finished product is installed as designed. Engineering calculations and proofs can be provided for specific examples if required.

If there are any specific question or concerns which are not outlined in the brief summary, please do not hesitate to contact Geobrugg for further clarification.

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