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Identification of riparian corridors (Streamside Management Zones) in areas where the erosion 'risk' and delivery of sediment, woody debris and/or forestry slash from slopes to streams is 'high': management options for transitioning to a permanent cover of indigenous species.

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1. Introduction

While riparian corridors (Streamside Management Zones-SMZ's) are specifically mentioned in several New Zealand best practice documents, their use as 'buffers' for intercepting sediment, woody debris and forestry slash remobilised by landslides initiated during storms, is not mandatory.

Overseas, riparian buffers have been shown to significantly reduce the connectivity between the source of these materials and streams.

In Tairāwhiti, where there are riparian buffers comprising indigenous species, they have been shown to serve other useful functions by providing shade, a food supply for aquatic organisms – by increasing the biodiversity of indigenous groundcover and tree species – and an overall improvement in stream health (Parkyn et al. 2006).

The often-quoted benefits of retaining buffer strips for the protection of salmonid habitat in British Columbia (Canada) recommend that the width of buffer strips should be based on the value of the vegetation in reducing the inevitable increase in landslide occurrence following harvest and the potential hazard this could pose within and downstream of forests located in steep erosion-prone hill country (extracts from Forestry Handbook for British Columbia, 1983).

In British Columbia, the success of 'buffers' in intercepting sediment, woody debris and forestry slash remobilised by landslides initiated during storms is attributed to:

- Buffers comprise old-growth indigenous tree species that have been retained along stream corridors and protected for millennia.
- Buffers are configured to match slope factors such as steepness and length.
- Buffer strips vary from 20-100m in width, **extend upslope to a topographic break in slope, or include the entire floodplain.**
- Harvesting is restricted to small coupes located upslope of these buffers.

2. The present-day dilemma in Tairāwhiti

A combination of factors predisposes the East Coast region to erosion. These include:

- tectonic influences (e.g. earthquakes, uplift rates),
- geologic influences (rock type, degree of faulting and crushing),
- a dynamic climate influenced by tropical cyclones, and
- the recent clearance of vegetation from steep slopes.

Sediment is generated by shallow landslides, earthflows, rotational slumping and by gully erosion and is then delivered to streams and rivers where sediment yields are extremely high by global standards.

Together, the 3 major rivers in this region generate ~55 Mt of suspended sediment annually (Hicks & Shankar, 2003). This amounts to ~0.3% of the total global suspended sediment input to the ocean (from ~0.003% of Earth's total land area).

Protective buffers comprising mature stands of indigenous vegetation are absent along several thousands of kilometres of stream corridor located within hill country drainage basins where a high proportion of slopes are steep, and sediment mobilised during storms has a high probability of entering a stream channel.

Setbacks from streams were not a requirement in areas severely affected by erosion during Cyclone Bola (1988) after which ~100 000 ha of forest was planted in exotic species, primarily *P. radiata,* the bulk of which was planted within a 5-year period between 1992 and 1997.

Planting setbacks introduced in the National Environmental Standards for Plantation Forests (NES-PF) in 2018 and based on set distances from the centre of streams proved to be ineffective in preventing sediment and slash generated from forest cutover entering streams during two recent storms – Cyclones Hale (January 2023) and Gabrielle (February 2023).

The effectiveness of riparian buffers in intercepting sediment and woody debris during future storms will hinge on:

- The density, diversity and maturity of early colonising indigenous plant species at the time of such an event,
- A buffer width that appropriately matches slope factors such as steepness, length and surface roughness, and
- recognised pathways targeted to where sediment and slash would likely travel downslope of the source and into streams and not necessarily be required along the total length or both sides of a stream.

Had past lessons been heeded (Marden 2004) and had there been the foresight to include provision for setbacks as a condition for forests established post-Cyclone Bola, the damage incurred downstream of catchments during the latest cyclones would have been significantly reduced.

The challenge ahead is to remove exotic pines from streamside corridors and other high sediment producing parts of the landscape (e.g. gullies) and transition these locations to a permanent cover comprising indigenous species of sufficient width to intercept sediment, woody debris and forestry slash remobilised by landslides initiated during future storms.

3. Scenarios for transitioning stream corridors from exotic pines to an indigenous cover to create buffers that, over time, will increasingly reduce the 'connectivity' between sediment and slash derived from production forests and streams.

NOTE:

(1) each scenario assumes the absence of an effective buffer within areas of production forest yet to be harvested.

(2) each scenario is premised on the concept that the 'connectivity' rating between a slope and a waterway (e.g., high, medium, low, negligible, zero) is more important than slope 'susceptibility' as not all slopes deemed to have a 'high' or greater susceptibility to erosion will necessarily contribute sediment and slash to streams.

(3) the 'connectivity' rating will likely be based on Hugh Smith's latest model which is for shallow landslides only and does not include a susceptibility rating for deeper-seated slope failures – such as earthflows and rotational slumps – or for gullies to contribute sediment and slash to streams, and for which additional data bases will be required.

Scenario 1: Removal of pines from streamside areas in locations where the connectivity between slopes and streams is deemed to be 'high' and where there is potential for sediment and slash to enter streams **is not permitted at the time of harvesting BUT their removal will be a requirement at some later date.**

It has been suggested that by limiting the size and location of areas permitted to be harvested (coupes) at any one time would significantly reduce the potential supply of sediment and slash to streams. This is unlikely, because there remain significant areas of the current rotation of pines located along stream corridors where, irrespective of coupe size restrictions, these are the sites where the potential to generate and deliver slash to streams after harvest, and well into the future, is greatest.

Furthermore, the introduction of coupe sizes could have unintended consequences if introduced before exotic pines are removed from all streamside locations recognised as being susceptible to erosion, and where sediment and slash have a high probability to enter stream channel. For example,

- If the size of a coupe does not incorporate areas of trees located along stream corridors and they are not permitted to be harvested at the same time as the remainder of the setting located further upslope, then at some later date if the unharvested trees are required to be removed, they will likely be too large and therefore too dangerous to fell (i.e., H & S issues) and too difficult to extract using conventional machinery.
- Furthermore, to return to an area that was harvested and replanted some years earlier, just to retrieve streamside trees, will likely require existing roads and landings to be reinstated/upgraded. In places the road network may need to be extended, and new landings constructed which may prove to result in unnecessary additional environmental disturbance, be impractical and almost certainly uneconomic to do so.

- Additional unintended consequences of imposing a coupe size concept that restricts/ delays the removal of pines planted along streamside corridors include:
    - trees left along stream corridors for any length of time will be vulnerable to windthrow and stem snap rendering them uneconomic to retrieve thereby providing some forest owners with the excuse not to harvest.
    - abandoned stands along waterways will eventually make up a significant component of the woody debris in streams for decades to come. Toppled, full-length trees will become more problematic in that, in addition to slash (waste wood), they will make up a significant component of all woody debris transported downstream of forests.
    - full-length trees are more likely to wedge into the banks of narrow channels to form debris dams behind which slash can accumulate with the potential to form flood flows and, in some instances, debris flows. Entire length trees are also more likely to jam against bridges with the risk of causing these structures to fail.

Scenario 2: Removal of pines from streamside areas is permitted at the time of harvesting. Settings in locations where the connectivity between slopes and streams is deemed to be 'high' and where there is potential for sediment, slash and mature trees to become a significant component of woody debris in streams.

- First and foremost, with the removal of mature trees from the most vulnerable of slopes at the time of harvesting, many of the adverse consequences listed above will be alleviated both in the short and longer term. This will allow the transition from pines to an indigenous cover to commence earlier than in Scenario 1.

Scenario 3: The removal of pines from streamside locations is staged to coincide with the harvest schedule i.e. when the trees reach maturity.

So, within any one forest the transitioning of streamside locations where the connectivity between slopes and streams is deemed to be 'high' and where there is potential for sediment, slash and mature trees to become a significant component of woody debris in streams, would be 'staged.'

- This is the most practical of the scenarios as it provides forest companies with the certainty that areas already established in pines will be allowed to be retrieved and to plan/design the road and landing network accordingly.
- Although this may in places involve the harvesting of whole slope lengths at any one time it avoids unnecessarily having to go back to said settings at some later date and re-disturbing the landscape a second time.

Scenario 4: The removal of pines from streamside locations is to be fast tracked – i.e. bringing forward the harvesting of settings in locations where the connectivity between slopes and streams is deemed to be 'high' and where there is potential for sediment, slash and mature trees to become a significant component of woody debris in streams.

- Disadvantages of this scenario would likely include the injection of large volumes of sediment and slash into multiple waterways within a brief period. Should a storm coincide with the felling of extensive reaches of stream corridors it could result in disastrous off-site impacts.
- Creating access through standing pines before they are due to be harvested, solely to remove streamside plantings would be costly, require costly maintenance until the rest of the stand reaches maturity, and exposes said stands to potential windthrow along road corridors.
- Advantages would be the removal of pines from extensive reaches of streamside corridors and commencement of the transitioning of these areas to an indigenous cover sooner than would be possible by a staged approach. Other environmental benefits such as improvements in water quality and stream biodiversity would occur across multiple drainage systems sooner.
- The difficulties and consequences of having to deal with an initial and large volume of slash would in the short term be severe but decrease noticeably sooner than for any of the other scenarios.

Scenario 5: Mature pines established in streamside locations are to be retained to mitigate further erosion

- On a large scale – that is, along extensive reaches within forested catchments and across multiple tributaries – this is not a clever idea.
- Tall trees on steep slopes adjacent to streams will be subject to windthrow or eventually die and become a constant source of woody debris for several decades to come.
- Full-length trees are more likely to wedge into the banks of narrow channels to form debris dams behind which slash can accumulate with the potential to form flood flows and, in some instances, debris flows.
- Full length trees are also more likely to jam against bridges with the risk of causing these structures to fail.
- On the plus side, as old age stands thin out, the canopy will open providing more moisture and sunlight to reach the forest floor where indigenous species will over time re-generate.

Scenario 6: Another well-established rotation of pines (2-yrs and older) has been planted on cutover located along streamside locations where the connectivity between slopes and streams is deemed to be 'high' and where there is potential for sediment, slash and mature trees to become a significant component of woody debris in streams.

- Not much can be done. Trees too old to remove prematurely other than by spraying. Best left to grow to maturity and permitted to be harvested as part of a staged retreat in line with a planned forest harvest schedule.
- Depending on what proportion of streams within each catchment have already been reestablished, slash at the time of harvesting will again become an issue in 25+ years' time.

Scenario 7: Pines re-established on cutover within 2 years of harvesting are required to be removed from streamside locations where the connectivity between slopes and streams is deemed to be 'high'.

- Advantage is that their premature removal will begin the transition process towards the development of a buffer – essentially comprising indigenous vegetation sooner. Thus, by the time settings located upslope of buffers and scheduled to be harvested in ~25+ years, recolonisation and growth of indigenous species in streamside locations will likely have developed sufficiently to a stage capable of mitigating further delivery of sediment and slash to streams.
- Costly to do but with today's technology and use of drones, individual trees can be targeted without causing undue damage to the indigenous understory.

4. Summary

- The rate of harvest and the setting of coupe size limits for areas likely to remain in production forest are policy decisions, as are decisions regarding the timing and method of removal of pines (e.g., harvest, poisoning etc.) from riparian areas and consequences should existing mature trees and new plantings be permitted to remain in streamside locations where they are highly likely to contribute to the slash load for decades to come.
- Options for transitioning these areas to a permanent cover of indigenous species may include passive reversion (i.e.. natural regeneration) vs managed reversion through planting seedlings or a combination of both strategies (see Appendices 1 and 2 for further information and relevant references).
- Following the removal of pines, and to ensure that the recovery of a groundcover of indigenous species occurs as quickly as possible, riparian margins will require post-harvest management – particularly of wildling pines, weeds and include pest management for at least the first 5-years of the transition period.

- The effectiveness of a groundcover comprising indigenous species in preventing erosion will not be realised for several decades. During this transition period there will be further episodes of landslide occurrence resulting in the remobilisation of residual slash with the potential to enter waterways. However, over time, there should be a noticeable reduction in the accumulation of both pine slash and whole-length trees in watercourses located within areas that remain in production forest and therefore less likely to exit forests onto private property downstream of forests.
- The pace at which any reduction in the volumes of sediment and slash exiting forested areas is likely to become apparent will be dependent on the scale (length of stream channels required to transition) and the duration it takes to fully implement the transition of areas where there is potential for sediment, slash and mature pine trees to become a significant component of woody debris in streams.

5. Identifying slopes with high erosion risk and connectivity

The Smith et al. erosion susceptibility/connectivity model is to be used to identify slopes where the erosion 'risk' and delivery of material from slopes to streams is likely to be greatest.

This model is a computer-based generic simulation that includes a calculation of sediment runout distances between the sediment source (landslide scar) and the base of a slope.

This is premised largely on stope steepness and length and where it is likely assumed that at the base of all slopes there is a stream channel.

However, this is not the case everywhere as in the real world there are other low angle landforms located between the base of a slope and a stream channel where a significant proportion of the volume of runout sediment and slash can potentially settle to form an **alluvial fan** and remain in long term storage with little potential to reach a stream **i.e., low connectivity.**

- For example, reports on landslide occurrence on **forest cutover** show that on average only 33% of landslides initiated on steep slopes reach a stream channel whereas the material remobilised by 67% of landslides either remained on slope or accumulated at the base of slopes as fan deposits (Marden et al. 2023).

Similarly, does the 'connectivity' component of this model factor in the significance of other landscape features, such as alluvial terraces and floodplains, in reducing landslide runout distances and hence their connectivity to streams, especially given the variable spatial distribution and extent of these features in different catchments?

If so, then where these landscape features are present, the **connectivity rating** of slopes identified as highly prone to the initiation of shallow landslides, and a stream may not be as high as perhaps the model might indicate. Instead, there may be no direct connectivity between these slopes and a stream and only minimal chance of sediment (and slash if present) reaching a stream. This does not mean that the erosion issues on slopes identified as highly prone to shallow landslides should not be addressed.

Furthermore, as this model is **unlikely** to have considered whether the stream at the base of each slope classed as high susceptibility and high connectivity is **perennial or ephemeral** and, by implication, capable/not capable of transporting material off-site to where it may become a hazard further downstream. *Is there therefore the need for a risk assessment/hazard potential factor built into set-back distance specifications for riparian buffers based on whether streams are ephemeral or perennial?*

- In a pastoral setting, whether a stream is perennial or ephemeral may not be relevant when prescribing a buffer width as this will be determined more so by where it is practical to establish a fence line on stable ground. Once a riparian buffer has been implemented fully and, assuming that stock exclusion is adhered to, then the risk of sediment discharge resulting in a hazard should be greatly minimised.
- Conversely, in a forest setting, irrespective of whether a stream is perennial or ephemeral, the setback distance set for a riparian buffer will need to consider that the part of the buffer closest to the pines will be destroyed. Often this is unavoidable as trees planted on steep slopes – and often where there were already signs of instability at the time of planting – many will be leaning downslope and, when harvested, they will inevitably fall into the buffer.
- It is therefore critical that the buffer width is sufficient to ensure that the part of the buffer closest to a stream is not disturbed and remains capable of intercepting sediment and slash before it reaches a stream channel.
- If the buffer is not of sufficient width, and is instead destroyed during successive harvests, then there will always be an influx of sediment and forestry slash into streams at the very time during a rotation of pines when cutover areas are at their most vulnerable to landslide occurrence and when a riparian margin is needed most, then is no point in insisting that one be established.

So, my query is *"should these stream and landscape attributes be factored into the 'connectivity rating' assigned to slopes at high risk to shallow landslides and be taken into consideration when prescribing set back distances for riparian buffers with the goal of mitigating the risk of sediment (and slash from forested areas) resulting in a hazard?"*

6. What constitutes an effective streamside buffer?

The pastured slopes shown in figure 1 are clearly susceptible to shallow landslide occurrence and are steep enough for material from multiple failures to enter streams (high connectivity). Some vegetation, possibly willow and poplar, has been planted along the stream but has likely been ineffective in preventing sediment derived from the slopes above from entering the stream. **Note**: These slopes have also been susceptible to both deep-seated landslides (deep depressions extending from the ridgeline to the channel) and shallow landslides (brown areas where cover bed materials are thin, dry out early and of low productivity) during previous storm events.

Figure 1. Effectiveness of a closed-canopy forest in preventing landslide initiation compared with similarly steep but treeless pastoral land within terrain classed as highly susceptible to the initiation of shallow landslides and where due to the absence of plantings the probability of sediment reaching a stream channel is also high, that is, high connectivity.

The setback within the forested area (see Figure 1) shows signs of the initial stages of natural reversion of indigenous vegetation. As is to be expected, these areas also show signs of recent landslide occurrence and will continue to do so after future storm events.

However, as the vegetation cover increases in stature and attains canopy closure, and the diversity of species (both groundcover and canopy species) provide an improved level of root reinforcement, the incidence of landslides in areas permitted to revert to an indigenous cover should decrease over time.

If these areas remain undisturbed or disturbance either by human activities and/or during future storms is minimal, they will form a permanent barrier able to intercept sediment generated by landslides initiated on slopes higher in the landscape.

This setback is, however, too narrow and will be trashed following harvesting so will serve no purpose in intersecting sediment and slash generated during the post-harvest period.

The goal should be to establish a **permanent** riparian buffer that is wide enough to retain its integrity to intercept sediment and slash from entering channels during successive harvests.

Additionally, as landslides will also be initiated within buffers during future storms, a buffer will need to be extensive enough to ensure that significant areas remain undamaged as these will then provide a localised seed source to ensure that the bare areas (landslides) recolonise and regenerate quickly.

Figure 2: An example of a buffer planned and implemented before forest establishment and with the foresight of providing a sufficiently extensive buffer that at the time when pines are harvested would intercept slash and sediment before it reached the channel (likely an ephemeral stream).

Figure 3: Pines restricted to above the topographic break in slope and below which a wide buffer comprising indigenous species has been retained.

Shallow landslides will always occur within buffers comprising indigenous vegetation and deliver sediment to streams, as was the case during Cyclone Gabrielle, but their occurrence and contribution of sediment to the channel have been significantly reduced.

Harvesting of the pines will result in damage around the upper fringe of the buffer and an increase in landslide occurrence is to be expected both within the buffer and because of slope failures initiated on the cutover further upslope.

Nonetheless, the buffer shown in Figure 3 is sufficiently wide and mature enough to reduce the amount of sediment and slash delivered to the channel than had there been no buffer present.

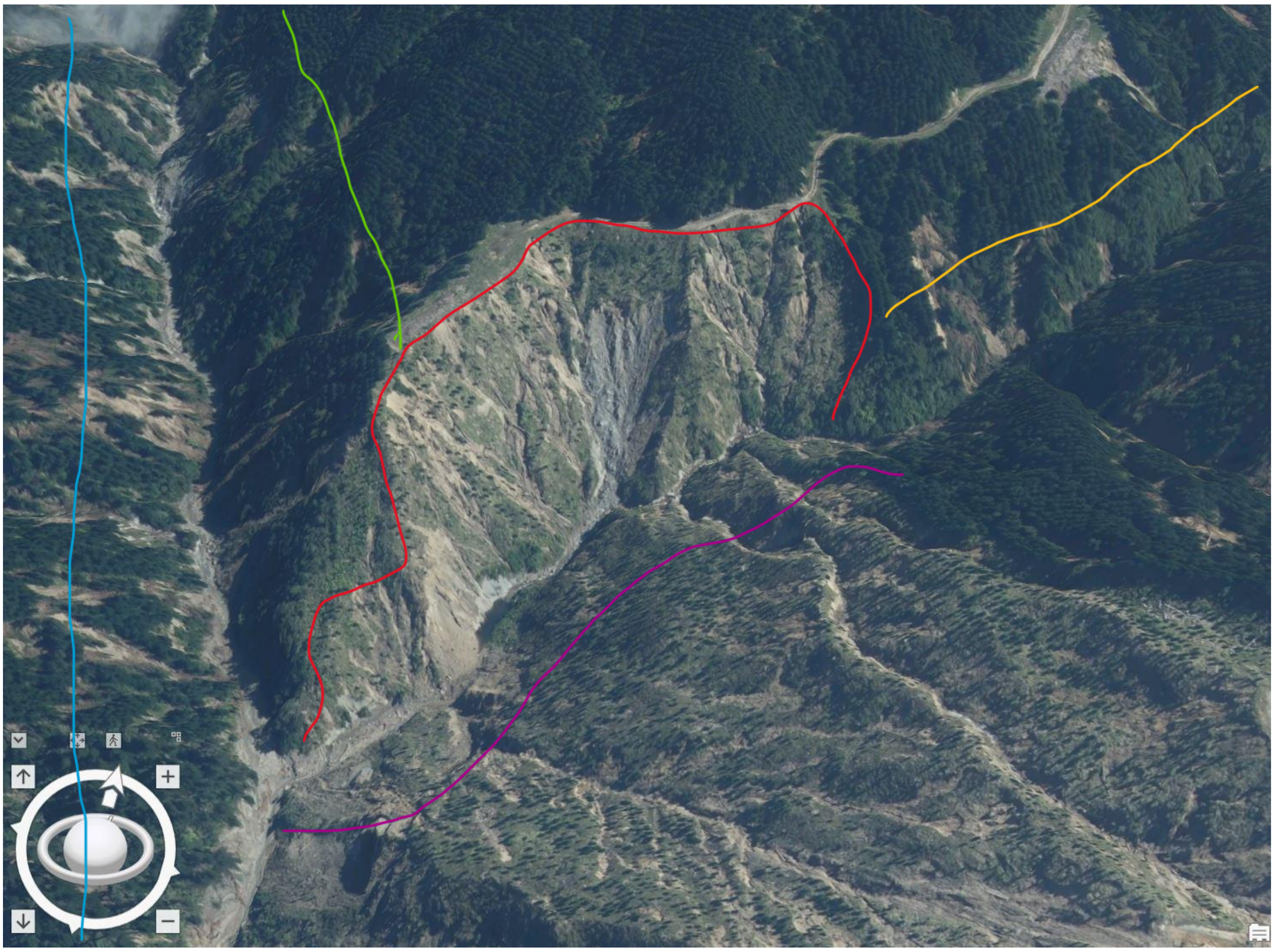

Figure 4: Scenarios for retaining and /or modifying existing buffers, for areas where buffers are most needed and for re-established areas where buffers areas where absent.

In Figure 4:

1) Orange line – the indigenous cover has not been cleared from the steepest slopes and is appropriately aligned with the topographic break in slope. **Maintain upper slopes in production pine.**
2) Red line – the buffer is absent on slopes where landslide susceptibility and connectivity are highest and where a permanent indigenous cover is most needed. **Solution: If recently re-planted, remove young seedlings and wildling pines, and leave to revert to a permanent indigenous cover.**
3) Green line – the indigenous buffer is in places aligned with the topographic break in slope but steep slopes below this break in slope have in places (down stable ridges) been planted with pines. **Solution: remove pines from slopes below green line at the time of harvest and leave to revert to a permanent indigenous cover. Maintain upper slopes in production pine.**
4) Blue line – the buffer along the base of slope is not continuous but instead is interspersed with pines. **Solution: remove pines from the lower slopes at the time of harvest and leave to revert to a permanent indigenous cover. Maintain upper slopes in production pine.**
5) Purple line – there does not appear to be an obvious unplanted buffer of sufficient width. **Solution: spray or hand pull young pines and begin the reversion process now rather than at harvest in another ~27-yrs time. Maintain upper slopes in production pine.**

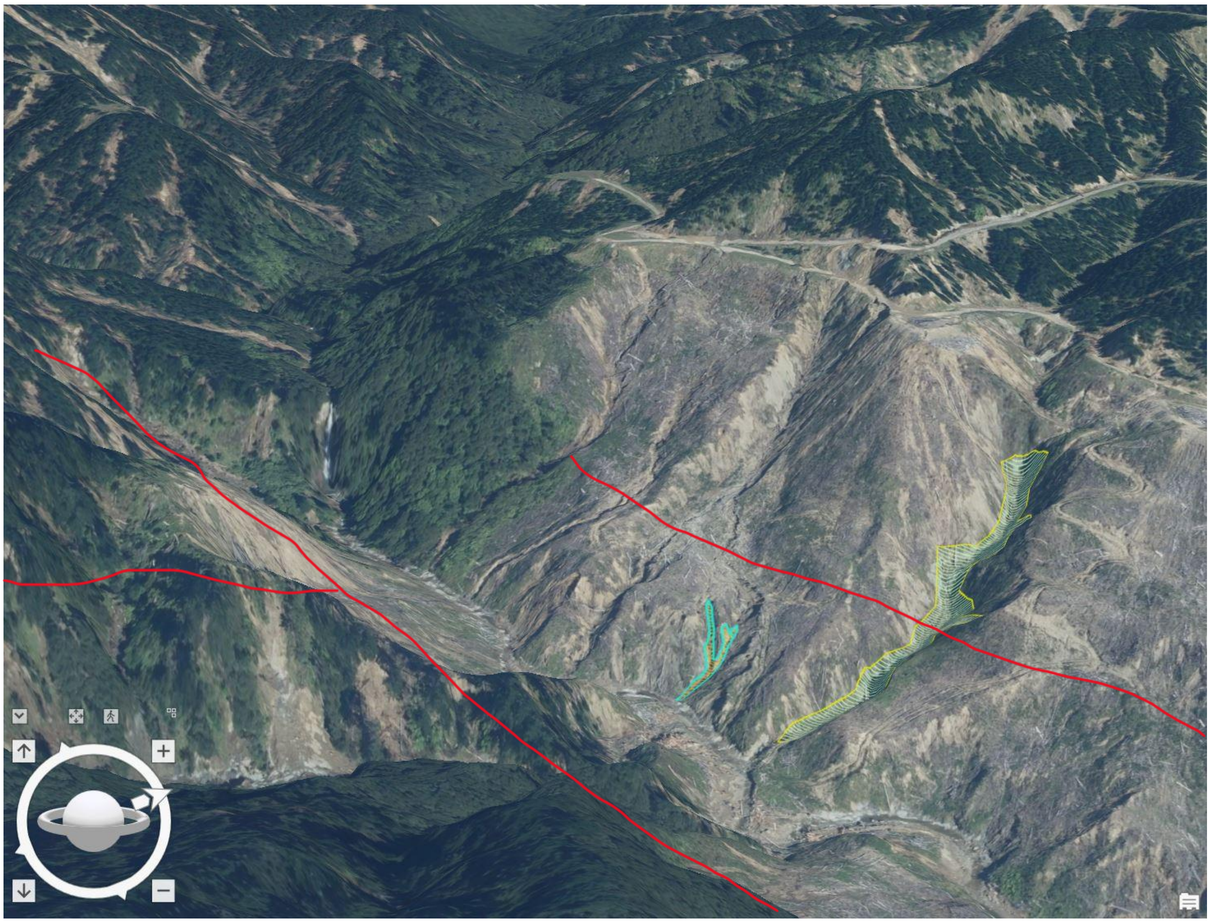

Figure 5: Absence of buffer below topographic break in slope (red lines) where it is most needed.

Solution: Do not replant pine below mid-slope break in slope and leave to revert to a permanent indigenous cover. Maintain upper slopes in production pine.

Buffers in pastoral settings

- Though small landslides initiated on **pastoral hill country** are more prevalent than large landslides, unless they are initiated on a steep slope located immediately adjacent to a stream channel, they often do not have sufficient volume to gain enough momentum to reach a stream channel. On average, less than 25% of the sediment they generate is delivered to a stream channel (Jones & Preston 2012), but this can vary with slope steepness and roughness, distance of slope from streams, presence of terraces or a floodplain to intercept sediment, and volume and moisture content of the displaced material.
- Conversely, a small number of large and deep-seated landslides on east facing slopes (Figure 6) are more likely to travel a greater distance downslope and deliver several magnitudes more sediment than a multitude of shallow landslides on slopes less impacted by landslides.

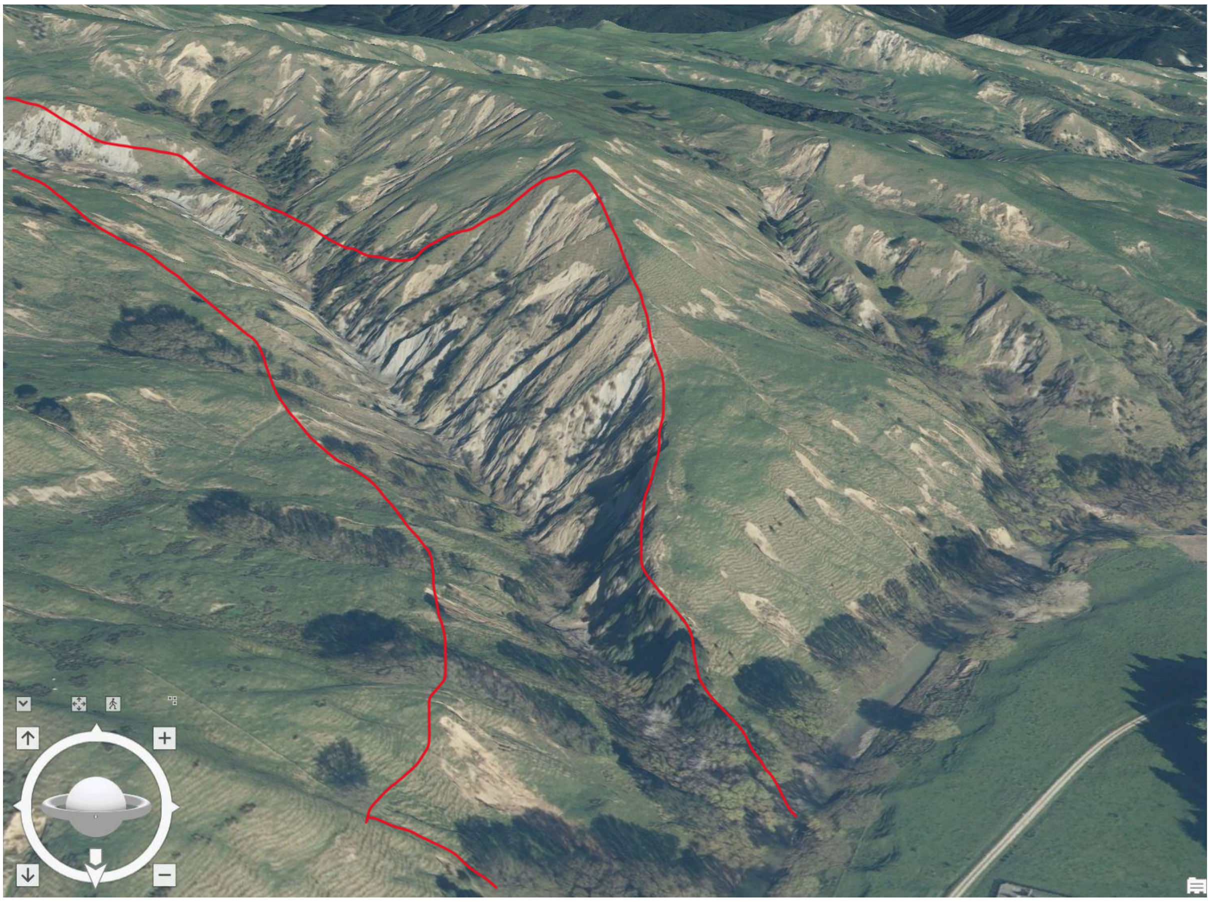

Figure 6: Identifying areas of high erosion susceptibility and connectivity to streams where riparian buffers in pastoral settings would reduce further erosion and sediment supply to streams.

Difficulties of retrospectively establishing riparian buffers in a pastoral landscape include:

- areas will need to be fenced
- finding a practical and stable fence line such as along a topographic break in slope
- unless reverting species are present and reasonably widespread then indigenous reversion is unlikely and, at best, will be patchy
- cost of fencing
- planting costs: options might include the planting of indigenous seedlings such as mānuka/kānuka on the worst eroding east facing slopes and a woodlot of commercially viable timber species on the lesser vulnerable west facing slopes with permission to selectively harvest individual trees or in small coupes as part of an approved farm plan set in place before planting commences
- pest and weed control.

7. Gully erosion and remediation options

Status of gully erosion as in 2017

- When last documented in 2017 there were 601 fewer actively eroding gullies than in 1997, 74% of which stabilised following the establishment of pines.
- In 2017 there were 1864 actively eroding gullies within Tairāwhiti of which 741 occurred on pasture, 741 in exotic forest, 119 in indigenous forest and 263 in shrubland.
- 1299 untreated gullies (69% of 1864) were within areas designated as LO3A (Marden & Seymour 2022).

Note: MPI (Malcolm Penn) undertook a spatial analysis of this gully database for the Ministerial Inquiry on Land Use (MILU) Report Response –Gully Watersheds Potential for Inclusion as “Purple Zones” (see Appendix 3).

Examples of treatment options for gullies on pastoral land

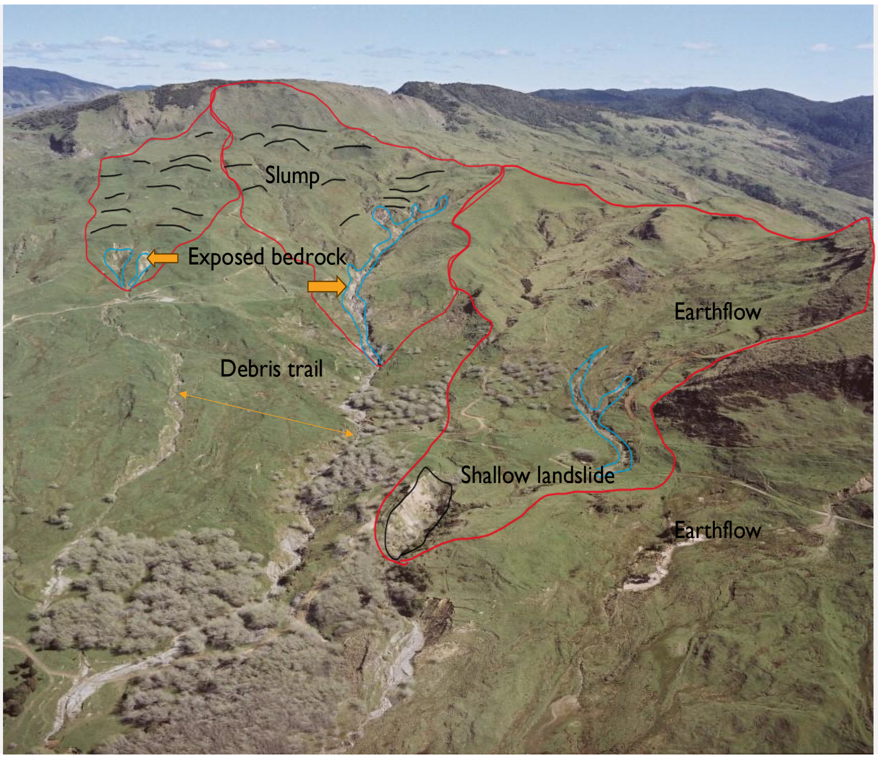

Figure 7: Small linear gullies on farmland.

Treatment option: extensive pole planting across the watershed, especially earthflows (the source of ground water emerging as springs, seeps) and within gullies.

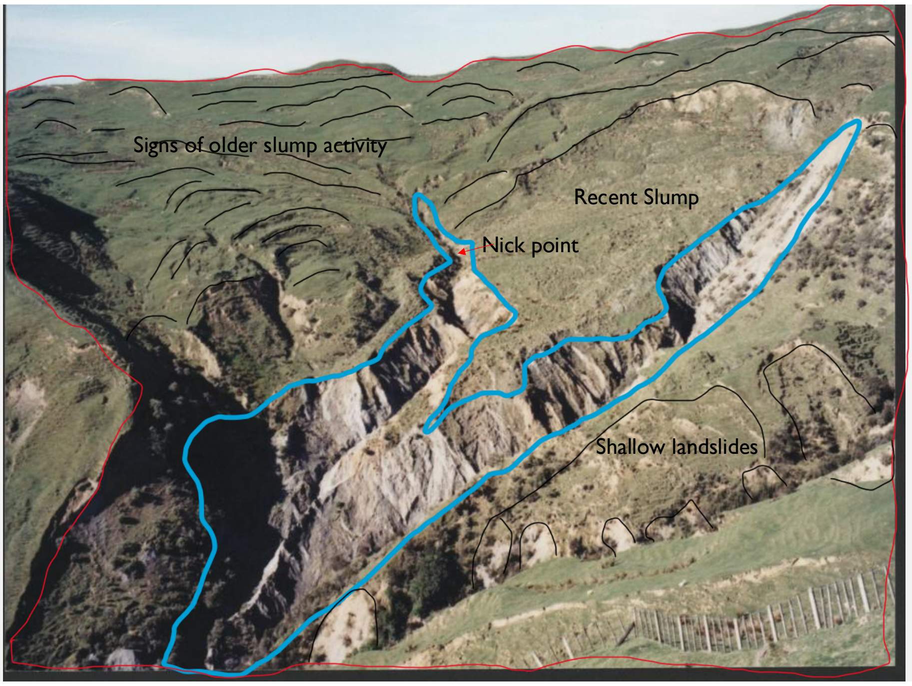

Figure 8: Larger incised gully located at the base of a sizeable watershed area that is showing signs of past and recent slope movement. **Gully is too deep to stabilise using poles.**

The most practical treatment option is afforestation of the entire watershed with pine or other woodlot species that at the time of canopy closure will significantly reduce runoff into this gully and arrest its development. If this gully remains untreated it will increase in size and cause further destabilisation within the watershed up to the ridgeline.

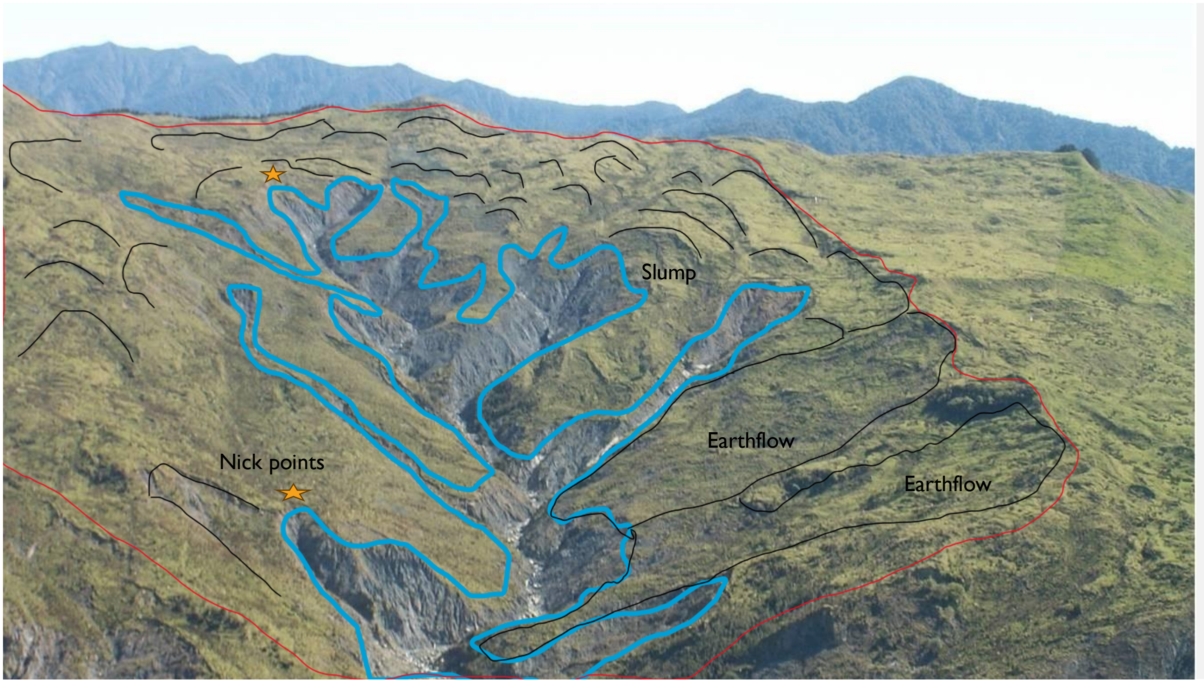

Figure 9: Multi-headed gully progressively expanding upslope towards the watershed divide.

Located in an area underlain by weak lithologies where the watershed is dominated by earthflows and rotational slumps. Sub-surface (i.e.. groundwater) is likely the main source of water lubricating earthflows and slumps and, together with rainfall, is causing the gully to deepen which further destabilises the surrounding slopes.

Option 1: The quickest and most practical solution to effectively slow the development of this gully, and as a pathway to returning this and other high-risk areas prone to gully erosion to a permanent indigenous cover, is a two-staged approach.

- Firstly, plant the watershed area surrounding this gully with pine but leave an unplanted buffer around the margin of this gully (~1 tree length of a mature pine). During one rotation (~27-30 years), trees will have significantly reduced rainfall runoff into the gully and, in combination with improved soil-root reinforcement, the slopes elsewhere within the watershed upslope of the gully will be less likely to fail.
- Secondly, at maturity, permit the pines to be harvested. Removal of the pine canopy results in the breaking-up of the needle duff and exposure of soil to light and moisture. This in turn will enable and enhance the germination of early colonising indigenous species of which there is a seed bank stored within the humus layer and allow reversion to take its course. The outcome may not necessarily result in the complete stabilisation of this and similar gullies but the pathway to achieving a permanent forest cover has begun.

Option 2: is to plant the watershed with indigenous (mānuka/kānuka) species. The period during which plantings, and the gully itself, will be vulnerable to the impact of future storm events (i.e.. window of vulnerability) will be longer (~16-years cf. 6-8 years for pines) but once a canopy has formed the interception function and root reinforcement effect will be similar (Ekanayake et al. 1997).

Option 3: fence and hope that reversion will occur. In this case this is **not** an option as:

- there is no sign of even small pockets of reverting species to function as a seed source
- once stock is removed, rank grass will suppress germinating indigenous species and grazing by hares and rabbits will further reduce the possibility that reversion will ever occur.

Badass' gullies

Figures 10 to 13 are examples of 'badass' gullies where there is no practical way of establishing extensive areas of vegetation capable of altering the hydrology sufficiently to slow their development.

For the gully complex shown in Figure 10, there is scope for increasing the existing areas of reverting mānuka/kānuka by planting seedlings or alternatively fencing this area and leave it to revert naturally.

In Figure 11, there is limited area surrounding this gully to bother planting but again, if fenced, the grassed areas may revert to an indigenous cover given that there is an extensive area of indigenous forest and potential seed source in the adjacent watershed.

Similarly, for the gully featured in Figure 12, remaining areas in pasture should either be planted or left to revert and together with areas that reverted to scrub post-1990, and registered in the ETS, will likely qualify for C-credits.

While it is not practical to try alternative methods to stabilise this and other ‘badass’ gullies (e.g., brush layering, pelletised seeds, hydro-seeding etc.), there is the potential to offset lost revenue from grazing with revenue earned by retiring and transitioning erosion-prone pastoral land to a permanent indigenous cover.

The gully featured in Figure 13 is an example of where the gully occupies the entire watershed, and nothing can be done to arrest its development. ‘Badass’ gullies will remain a significant source of sediment for millennia (Herzig et al. 2011, Marden et al. 2012, 2014, 2018, and Marden & Seymour 2022).

For these and other ‘badass’ gullies located within pastoral and partially reverting shrubland, reforestation with pines should not be permitted because they will serve no purpose and instead, at any stage during a rotation, they have the potential to topple, be windthrown or if they remain unharvested, they will eventually be undermined as ongoing erosion at the head of gullies (nick points) continues to extend upslope towards the watershed divide.

Watersheds containing ‘badass’ gullies have no future potential either as farmland or as a production forest.

Most, but not all ‘badass’ gullies will be in areas classed as LUC VIII and as part of some of the worst of the VII land use classes.

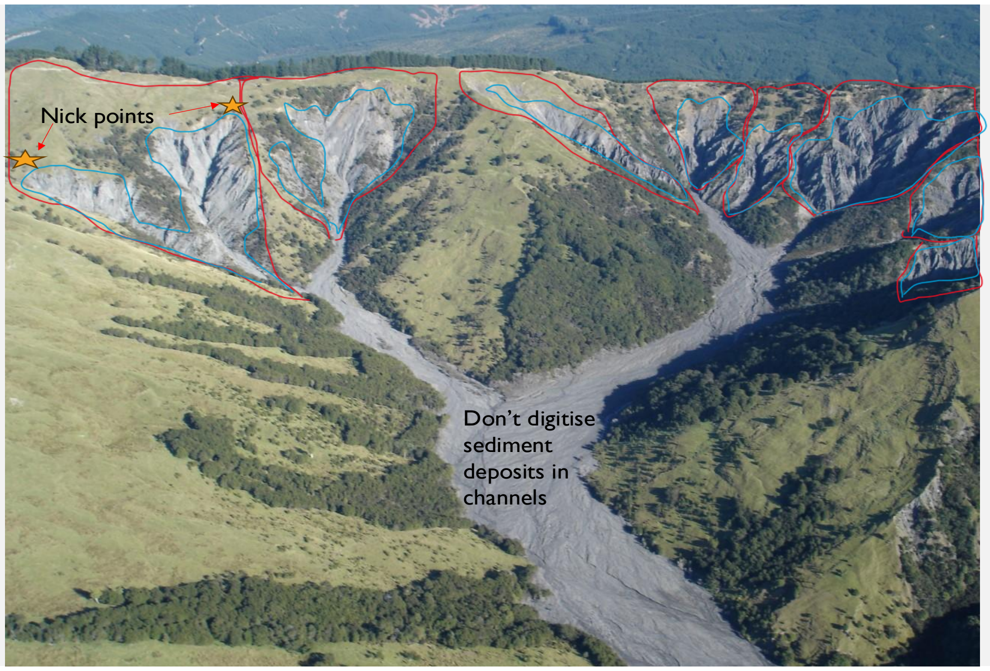

Figure 10: Extreme ‘badass’ gully erosion.

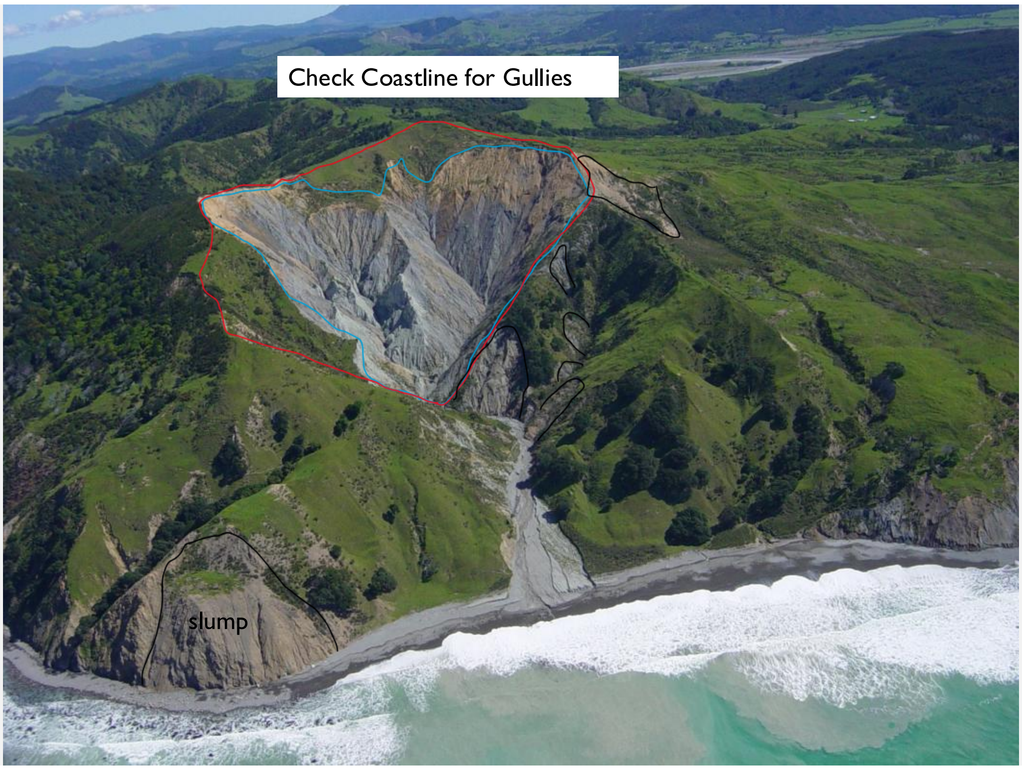

Figure 11: A coastal 'badass' gully

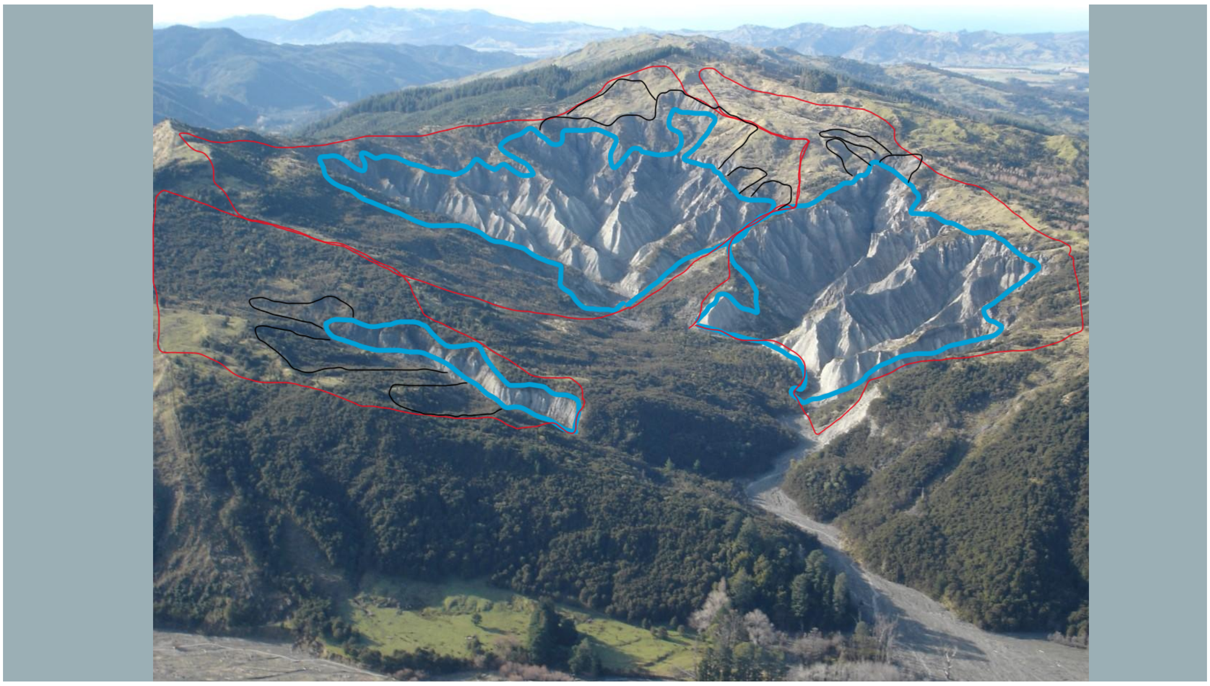

Figure 12: The largest of the 'badass' gullies. Barton's Gully, Wairongomai tributary, Waiapu Catchment.

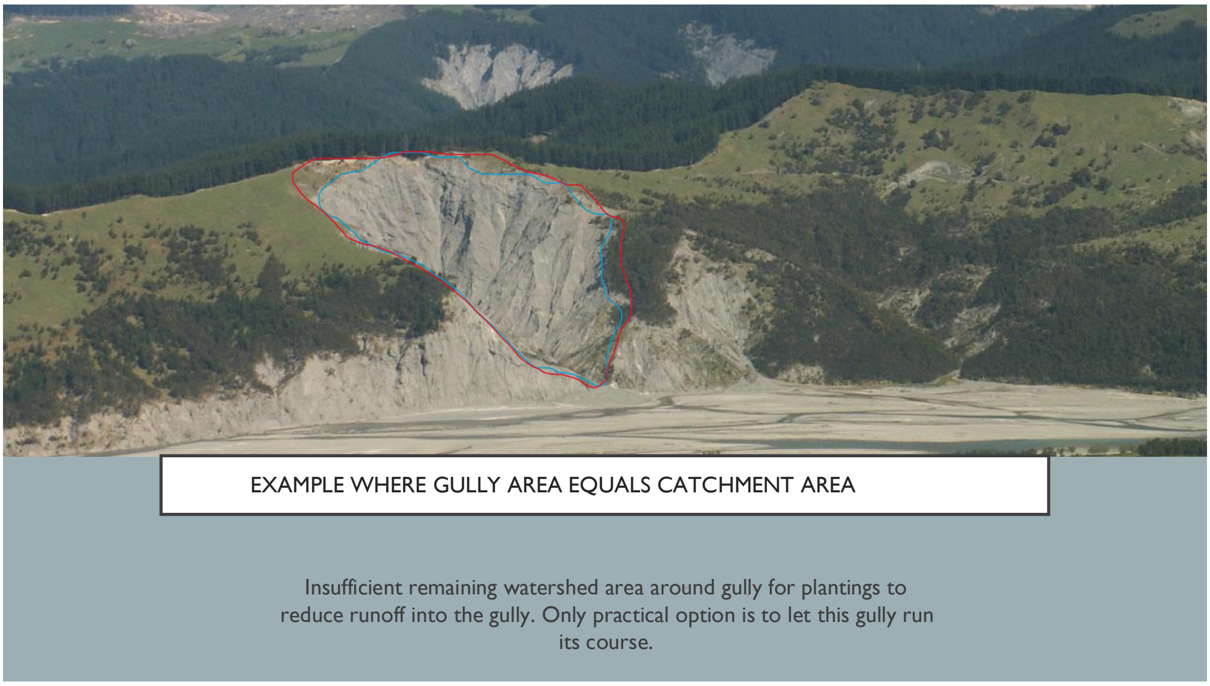

Figure 13: 'Badass' gully where gully area equals watershed area.

How many "badass" gullies (>10 ha) are there in the two geological terrains and the three major catchments (statistics from Marden et al. 2018).

Geologic Terrain	Gully Number	Composite Gully Area
Tertiary terrain	77	1538 ha
Cretaceous terrain	79	1454 ha
Total	**156**	**2292 ha**

Catchment	Gully Number	Composite Gully Area
Waipaoa	28	579
Waiapu	100	1929
Uawa	13	237
Other	15	246
Total	**156**	**2292**

Examples of successful gully remediation

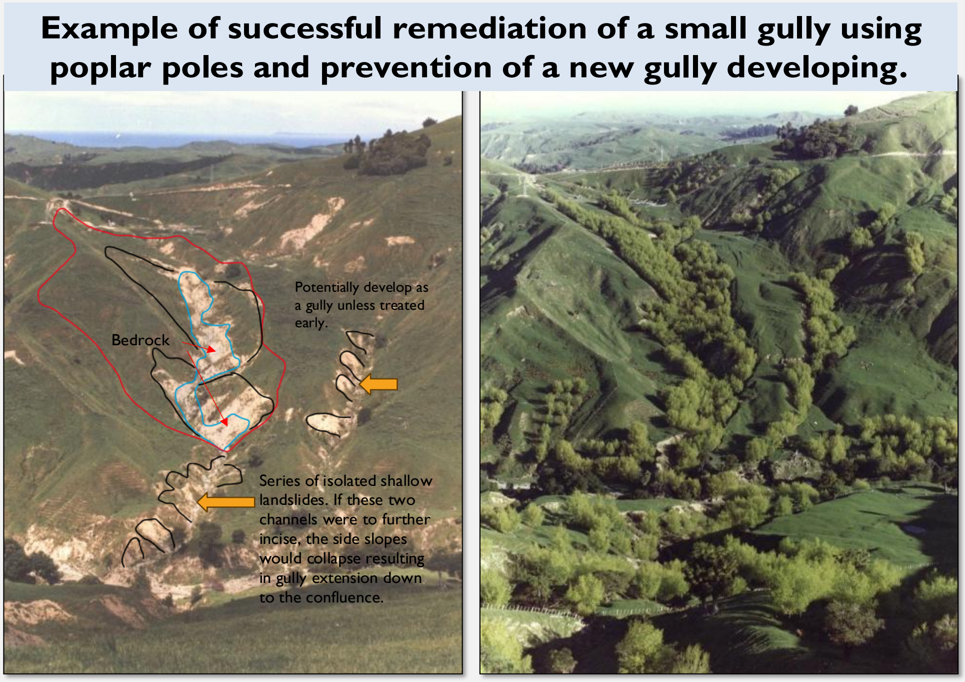

Figure 14: The message here is to **t**arget small linear gullies before they become untreatable.

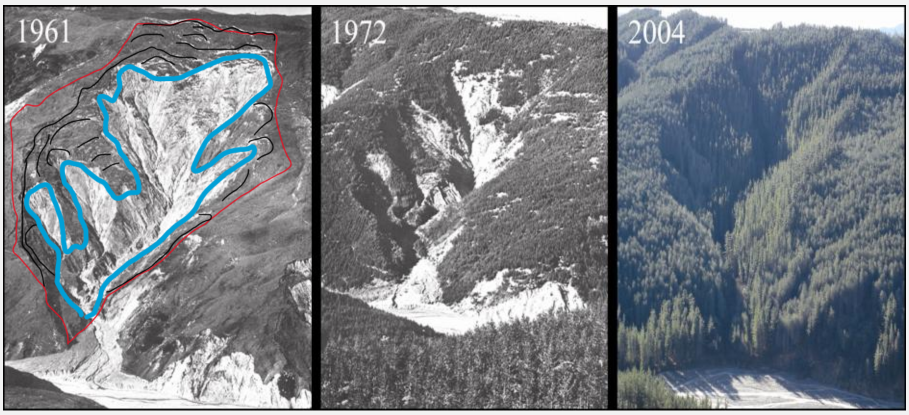

Figure 15. Pre- (1961) and post-reforestation (1972, 2004) photographs of a medium-sized gully in Te Weraroa Stream, Mangatū Forest, within the Cretaceous terrain. The elevation difference between stream level and the ridge at the head of this gully is 280 m. (The 1961 and 1972 photographs are courtesy of J. Johns and reproduced by permission of New Zealand Forest Research Institute Limited; 2004 photograph was taken by R. Hambling, Ministry of Agriculture and Forestry). M. Marden took the 2004 photograph. (Source: Marden et al. 2005).

In Figure 15, the successful stabilisation of this and other similar sized gullies is attributed to:

- planting the lesser-eroded interfluves surrounding this gully first (Pinus nigra was planted in 1962).
- returning 4 years later to plant the steeper and more severely eroding slopes immediately flanking the gully and within the gully itself (Pinus radiata was planted in 1966).
- By 1972 the effectiveness of the plantings in stabilising this gully were apparent and likely occurred earlier and coincident with canopy closure. Further within-gully plantings were undertaken on the remainder of bare slopes and of the fan (P. radiata planted in 1974).
- Before planting began, this gully was 7.6 ha in size, and by 1988 reforestation had reduced the area of active erosion to 0.8 ha.
- The latest photograph taken in 2004 shows that despite a major cyclonic event in 1988 (Cyclone Bola) this and similarly reforested gullies of this size, remained stable.
- This gully was harvested and replanted in the 1990’s. The recent spate of cyclonic events (2015–2023) had minimal impact on this forest, and no signs of slope failure were evident within this gully.

Example where afforestation has had negligible effect in stabilising a gully and where other vegetative treatments could provide long-term stability and reduction in sediment/ slash generation

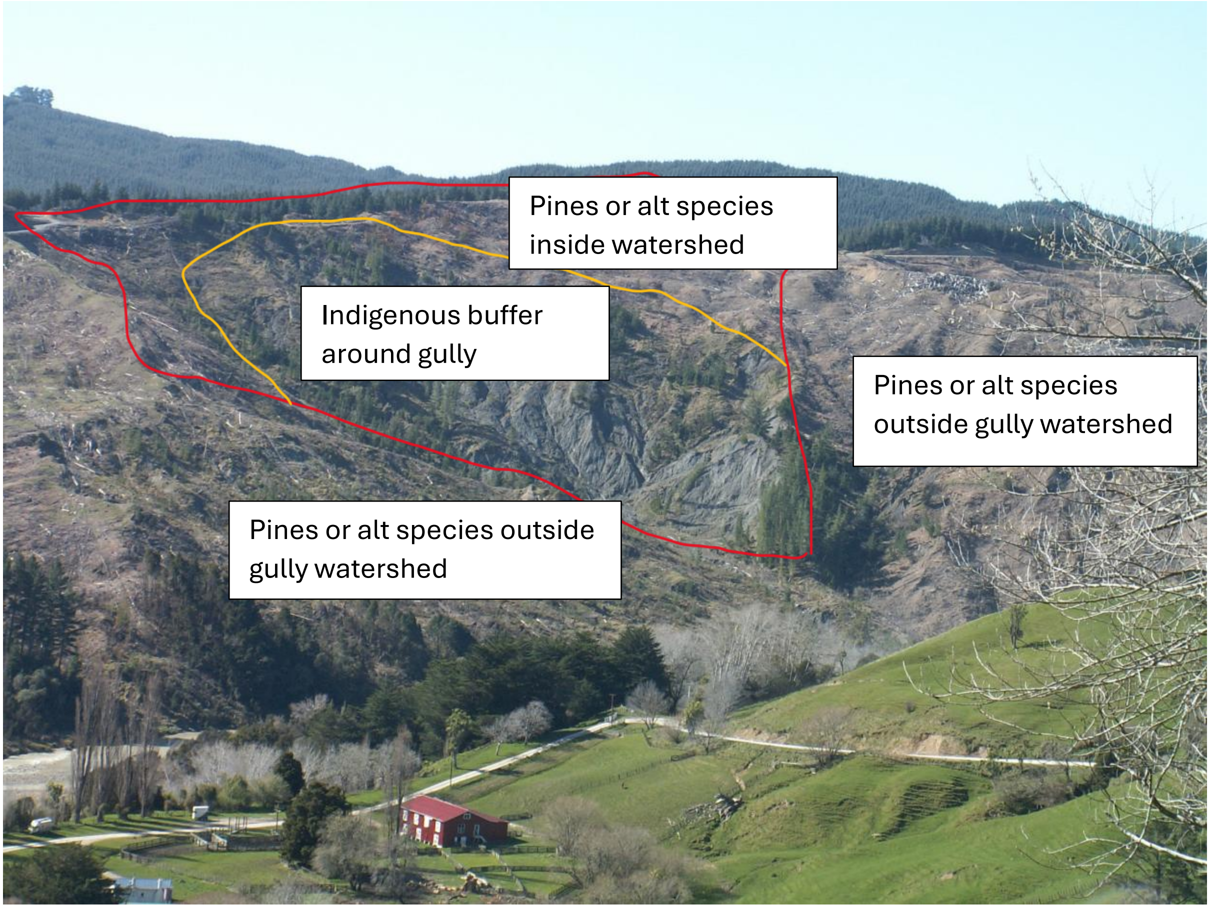

Figure 16: Gully planted with *P. radiata* and harvested 30-years later remains as a source of sediment. Red line is watershed surrounding this gully. Yellow line delineates approximate area below which a wide buffer comprising reverted and/or planted indigenous species would be required to enhance the stabilisation of this gully and reduce forestry slash falling into the gully during successive harvests.

Repeat episodes of forest removal will likely prevent this gully from fully stabilising. Preferred long term options could include:

- replant watershed in pine or alternative timber species with the prospect and permission to harvest but leave a wider unplanted buffer around the perimeter of the gully to facilitate reversion either passively or with supplementary planting of mānuka to achieve a permanent cover.
- leave the entire watershed to revert to an indigenous cover
- replant entire watershed in indigenous seedlings.

The key determinants affecting whether reforestation is an effective means of stabilising gullies include their size and shape at the time of planting; linear gullies are more likely to stabilise sooner than their amphitheatre-shaped counterparts.

For gullies ≤1 ha there is an 80 to >90% probability that they will stabilise within a decade of forest establishment, a 60% probability for gullies ≥1 and ≤5 ha in size, and for gullies ≥5 and <10 ha, an even chance of stabilising within a rotation (~24–27 years) of P. radiata (Marden et al. 2011).

The overall success of reforestation in ameliorating gully erosion on a large scale can be attributed to:

- the selection of fast-growing tree species (which are harvestable c. 24 years after planting),
- ideal growing conditions, and
- the planting strategy adopted. That is, gully stabilization was achieved first, by planting as much of the gully watershed area as physically possible and, second, by delaying within-gully plantings until there was a noticeable reduction in runoff and sediment supply to the channel as evidenced by channel incision and fan abandonment. This usually coincided with canopy closure, c. 8 years after planting.

Many, but not all gullies >10 ha, are too large and active to restabilise by vegetative means, including reforestation, because there is often insufficient watershed surrounding these gullies where planting or reversion would have an effect in reducing rainfall runoff significantly enough to slow their development. These gullies are essentially 'untreatable' with a high probability that many will increase in activity and size during successive storms (Marden et al., 2012). The larger and untreatable gully complexes will continue to dominate the sediment supply of the major river systems within Tairāwhiti for millennia and little can be done to offset or ameliorate their adverse impacts, either on-site or downstream (Marden et al., 2011).

8. Defining LO3B (Purple Zone') with inclusion of streamside buffers

Presumably, LUC VIII will automatically qualify as LO3B?

To assist in identifying riparian areas, use NIWA's river classification as both gullies and slopes with high susceptibility and connectivity to streams are predominantly aligned along stream channels.

Use LCDB to identify where riparian buffers already exist. If Gisborne District Council does not have the shape files in a format that can be intersected with aerial imagery and Hugh Smith's landslide susceptibility model, then ask Landcare Research and/or the Ministry for the Environment for them.

8.1 Streamside buffers

- Use Land Cover Database (LCDB) and aerial photography to identify where buffers already exist.
- Use Hugh Smith's shallow landslide connectivity model (based on slope steepness) and contours (LiDAR) to identify where there is **a marked break in slope.**

- Where it exists, capture this break in slope in GIS, catchment by catchment concentrating on zero, first and second order streams using NIWA's REC classification.
- In areas where there is no obvious break in slope adjacent to streams, i.e.. areas where slopes are ≤25 degrees and where shallow landslide occurrence is unlikely, then base the buffer setback distances to a minimum of the equivalent of a couple of tree heights so that felling of pines in the future will not trash the entire width of the buffer.
- These will be areas where the predominant landform adjacent to streams likely coincides with the toe of earthflows and slumps.
- Although these features are invariably highly connected to a stream their displacement is dependent on high soil moisture levels for extended periods of time and therefore only remobilise during periods of exceptionally high rainfall such as during major storms including Cyclones Bola and the combined rainfalls of Hale and Gabrielle.
- For earthflows under a full forest cover (i.e.. where the entire watershed has been afforested) (Figure 17), rates of downslope displacement are episodic, at glacier-pace and 2–3 orders of magnitude less than unforested earthflows (Zhang et al. 1993).

Figure 17: Successful treatment of earthflows after reforestation.

- Their contribution to the sediment load of streams is the least of all the erosion processes present in this region (Marden et al. 2012).
- Some – but not all – earthflows will remobilise following harvesting and contribute sediment to streams only where their toe reaches the edge of a stream. While it is not possible to prevent this, it is possible to reduce the volume of trees and forest slash likely to enter a stream channel.
- Prescribing a set-back distance greater than the equivalent of ~2 tree heights is in anticipation that half the width of a buffer will be trashed during harvesting but at least half the width of said buffer will remain intact. The trashed section of the buffer will regenerate between successive rotations.

- Most, but not all, forests established on earth flows will likely be harvested using ground-based machinery, so to retain the function of a riparian buffer, machine tracking through buffers should not be permitted.
- For hauler-based settings, the dragging of logs through or over riparian buffers should also be banned OR if the removal of trees from streamside locations is critical to preventing them falling into a channel, then log extraction will need to be localised to a limited number of narrow corridors through the buffer.
- Earthflows located on pastoral land are best treated by distributing pole plantings in sufficient numbers across the entire flow to de-water them and prevent moisture levels increasing to the point where earthflow materials become saturated and reach a threshold at which downslope movement is likely to recur. The planting of poles along the toe slope of earthflows will eventually end up in the stream channel so these too should be set back at least 20 m from the stream edge.

8.2 Buffers around gullies

The identification of where in the landscape and the width of buffers likely to be required surrounding gullies will require detailed mapping at ≤ 1: 10 000 scale. I suggest using the 2017 gully database (Marden & Seymour 2022) to identify their location and intersect with Hugh Smith's connectivity model which will highlight areas of high erosion susceptibility to the initiation of shallow landslides around the headwall scarp and along channels draining downstream of gullies.

Note No 1: MPI is currently re-mapping gullies post-Cyclone Gabrielle which will identify:

- new gullies initiated since 2017 and likely during Cyclones Hale and Gabrielle
- pre-existing gullies that had been successfully stabilised under a forest cover but failed post Cyclones Hale and Gabrielle
- gullies that remained stable despite these cyclones

Note No. 2: MPI, in alignment with Gisborne District Council's goal to use the Uawa Catchment as a test case, are aiming to complete the mapping and analyses for gullies within Uawa Catchment by the end of April 2024. The availability of shape files and level of analyses achieved within this period to be confirmed with Malcolm Penn @ MPI.

By June 2024, the regionwide distribution of actively eroding gullies will have been completed and a draft report of the findings submitted to MPI. The content and results to be presented in this report will be comparisons of the changes in distribution of gullies since 2017 (Marden & Seymour, 2022) across 2 different geologic terrains, by catchment, by vegetation type and include recommended treatment options based on their size and location and on past learnings of the successes/failures of past treatment.

Note No. 3: For the Ministerial Inquiry on Land Use (MILU) Report Response –Gully Watersheds Potential for Inclusion as "Purple Zones", MPI used a fixed width based on the size classification of gullies as a surrogate for identifying land unsuited to primary production ("purple zone"). These areas were then intersected with the following spatial datasets: LUM, Erosion Susceptibility Classification, LINZ property titles, Gisborne District Land Overlay 3A, and Māori Land (Online), to derive a percentage of land likely to be required around gullies and potentially re-classified as "Purple Zone" (see Appendix 3).

- Although these databases are at varying scale, each will be of use in contributing to the identification of site-specific locations where buffers will be required and in time capable significantly reducing the volume of sediment, fallen trees and forestry slash likely to enter a stream channel.
- As the landscape around gullies is highly variable and signs of potential gully expansion can often be observed at considerable distances further upslope of the main feature, the assigning of a fixed width buffer will not consider that many gullies will inevitably expand in size. A more certain way of identifying the area within which a gully may expand over time and will likely be confined to, is to identify the watershed boundary surrounding each gully. Depending on the gully size and its activity, a buffer set back should be based on a topographic change in slope which will either: (i) vary in width around its perimeter, (ii) require the entire watershed to be treated or (iii) there is insufficient area around a gully to establish a buffer.

8.3 Riparian buffers as a requirement of farm and forest plans

Using the latest available models, GIS databases, LiDAR, and aerial photography, I suggest that Gisborne District Council:

- produce a property-scale map of Tauwhareparae Farms showing the distribution of slopes identified as considerable risk of erosion and connectivity to streams (Smith model), the distribution of gullies (Marden 2018), current land uses (LCDB) and stream order (NIWA's river classification)
- for this property, produce a mapped outline of where riparian buffers along stream corridors and around margins of gullies may be a requirement under the proposed plan change and/or Catchment Management Plans
- present tutorials explaining the criteria/rationale/legal requirements supporting the transition of specific areas of individual properties from their current land use to a permanent indigenous land cover.
- use this exercise to kickstart discussions with the most affected primary sector groups and individual landowners to make it clear what is expected of them, by what date, in what format (paper maps or GIS format), and at what scale.

I have suggested Tauwhareparae Farms as it is mutual ground so to speak, it has similar landforms and erosion issues common to elsewhere within this region, and it encompasses significant areas of both pastoral farmland and forestry.

I am also aware that an exercise to better rationalise pastoral and forestry land uses across this property was commissioned a year or so ago and may be of use and indeed complement the findings of this proposed exercise. I suggest someone enquire as to the accessibility of the GIS-based maps produced for this exercise.

The initial interpretation of locations of riparian corridors and set-backs specifications would need to be done in-house. If there is not sufficient capacity to produce the final versions of maps/graphics in-house, then someone like Matene Blandford might be interested.

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10. Appendices

Appendix 1:

Effectiveness and/or Limitations of Different Vegetation Types in Mitigating Erosion

In New Zealand, both exotic and indigenous forests play a significant role in environmental improvement, not only in terms of reduced on-site erosion (Marden 2012) and rates of sediment generation (Marden et al. 1995, 2008, 2011, 2012), but also through improvements in water quality during the rotation (O'Loughlin 1995; Parkyn et al. 2006; Quinn & Phillips 2016), and increased rates of carbon sequestration (McLaren 1996).

The understanding of how vegetation contributes to slope stability and erosion control is relatively well advanced. In general terms, the above-ground components of vegetation (canopy) reduce the ability of rainfall to cause slope failure through the processes of interception and evapotranspiration, while the below-ground components (roots) provide mechanical reinforcement and are how trees extract soil moisture from the soil to reduce pore water pressures.

These processes become most effective when canopy closure (canopies of individual trees touch) and full-root occupancy (lateral roots of adjacent trees overlap) first occur. The rate at which canopy closure and root occupancy occur is largely determined by plant spacing, growth rate and silviculture regime.

During small to moderate storm events a mature forest cover provides adequate protection against rainfall-triggered slope failures and is an effective means of improving the stability of slopes. The degree of protection is, however, limited during the more severe events when rainfall is sufficient to exceed the ability of stands of mature *P. radiata* and remnant areas of closed-canopy reverting forest/shrubland to remain anchored to slopes.

Shallow Landslides

Researchers have attempted to quantify the effectiveness of different vegetation types in mitigating the impact of relatively infrequent but large magnitude storms against landslide initiation. Much of this research has focused on *P. radiata* (radiata pine), kānuka (*Kunzea ericoides* var. *ericoides*), mānuka (*Leptospermum scoparium*) and space planted poplars as the species used most widely for erosion control in this region.

The effectiveness of *P. radiata* for protection against shallow landslides in New Zealand is well documented (O'Loughlin 1984; Phillips *et al*. 1991; Marden & Rowan 1993).

Less well known is the role that mānuka/kānuka, shrubland species endemic to New Zealand and an early coloniser of harsh sites, plays in soil conservation and erosion prevention (Marden & Rowan 1993; Bergin *et al*. 1995; Rowe *et al*. 1999) and that of indigenous forest (Marden & Rowan 1993; Parkner *et al*. 2007).

The following is a summary of those findings.

Comparisons of storm-initiated landslide densities and different vegetation types show that there is minor difference in the protective value between different closed-canopy evergreen forest species, but that forest age has a significant effect on the number of landslides initiated. For example, areas under indigenous forest and exotic plantations >eight years old were 16 times less susceptible than pasture and exotic pines <six years old and four times less susceptible than regenerating scrub and exotic pines six to eight years old to landsliding during Cyclone Bola (Marden & Rowan 1993).

In another study of landslide damage to fully stocked stands of reverting kānuka and mānuka 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 (Bergin *et al*. 1993, 1995).

Similarly, following the Manawatu storm (2004), landsliding under forest was 90% less than that under pasture and 80% less than that under scrub (Dymond *et al*. 2006).

These figures show that a forest cover affords considerable protection against the initiation of landslides and is consistent with process-based research that shows there is minor difference in the magnitude of interception loss, as a percentage of rainfall, across different, closed-canopy vegetation communities (Rowe *et al*. 1999).

Soils under a dense forest cover will therefore be less prone to rainfall induced landslides than similar soils under pasture and other vegetation types with an open or partial canopy such as young stands of pines and scattered, regenerating scrub.

Within forested areas, and particularly during extreme rainfall events, factors additional to the soil–water regime are also likely to have an influence on landslide initiation. These include stand density, root–system mass and dimension and the effectiveness of root-soil reinforcement.

Comparisons of excavated root systems of kānuka and *P. radiata* revealed that although the roots of *individual* kānuka were smaller than those of *P. radiata* at all stages of growth, the difference in total root mass was more than compensated for by the higher stand densities of the kānuka. Thus, the annual rate of root production of *stands* of regenerating kanuka exceeds that of *P. radiata* for the first nine years of growth (Watson *et al*. 1995).

Consequently, the calculation of slope safety factors (a measure of a slope's resistance to failure) showed that slopes with a dense stand of regenerating kānuka were 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 (Ekanayake *et al*. 1997).

For forests established in areas underlain by Tertiary-aged lithologies, site-specific factors have a significant influence on landslide susceptibility and occurrence during storm events including:

- slope steepness, with most failures occurring on slopes >26º.
- slope aspect, landslide occurrence tends to be greater on slopes with a northeasterly aspect and is a function of the prevailing direction in which many storms track.
- Slope concavity, where concave slopes steepen in an upslope direction, are prone to shallow landslide initiation particularly on the uppermost and steeper part of a slope (e.g. sandstone bluffs and headwall scarps of 'relict' slumps and earthflows) or where there is a change in slope profile between concave and convex – which often coincides with the thinning of the cover beds – increasing their susceptibility to saturation.
- convex slopes are more commonly located towards the base of slopes where landslides are a common occurrence and more likely to connect with and deliver sediment and slash to streams.
- soil thickness and porosity – shallow and porous soils are subject to saturation during heavy and/or prolonged periods of rainfall.
- the presence of a sharp contact between the base of cover bed materials (soil, loess, volcanic ash, colluvium etc) and the bedrock surface at which most shallow landslides fail.
- insufficient soil depth for trees to develop a robust root network and inability of tree roots to penetrate and anchor cover bed materials to the underlying bedrock making them vulnerable to landslide initiation and windthrow (Schweinfurth 1967, White 1949).
- weaknesses within stratified bedrock (e.g. bedding planes between layered siltstone, sandstone, and mudstone) leading to 'slab failures' capable of displacing large volumes of bedrock and live standing trees en masse.
- the predominance of very thick, massive mudstone with minor alternating beds of sandstone and mudstone likely to have been weakened by crushing and folding associated with the SW-NE striking Akitio Syncline.
- undercutting of stream banks destabilising pre-existing earthflows and rotational slumps.

Earth Flows

There can be little doubt that the removal of the original indigenous forest cover increased the risk of earth flow initiation and that the absence of a forest canopy and lack of a dense network of intertwining roots in the subsoil is related to today's accelerated rates of earth flow movement on pastoral hill country (Marden *et al*. 1992).

Surface movement studies of a grassed earth flow complex showed that surface displacement rates are fastest during wet periods and moderately correlated with monthly rainfall (Zhang *et al*. 1993).

In an earlier study, it was shown that the difference in movement rates between reforested and grassed earth flows represents an order of magnitude reduction in erosion rate by earth flows after reforestation, with interception loss by the forest canopy being the principal contributing factor (Pearce *et al*. 1987).

Depending on planting density and growth rate, canopy closure within 8 to 10 years of planting pines reduces the soil water content for longer periods and consequently surface displacement slows appreciably (Pearce *et al*. 1987). At about the same time, the root systems of pines are known to develop both strong lateral structural roots, which may extend up to 5m from the root bole, and vertical sinker roots up to 2.1m deep (Watson *et al*. 1999).

Given that most earth flow displacement occurs along a basal shear plane typically 5–7m below the ground surface and at a depth exceeding that of the maximum root penetration of most forest tree species, it has been suggested that when trees are planted close enough, the roots of individual trees interlock to form a semi-rigid, reinforced layer that floats on the more mobile material beneath (Zhang *et al*. 1993).

Through its superior interception function, a closed canopy of evergreen forest affords the best option for stabilising mobile earth flows. However, the space planting of deciduous poplar and willow, in sufficient numbers, has also proven to be a useful treatment option, though on account of the wide variation in plant spacing used, its effectiveness has been more difficult to quantify and is largely anecdotal.

Irrespective of species, root density declines rapidly with depth and distance away from the stem. The success or otherwise of a vegetative treatment option for earth flows will therefore be determined ultimately by plant survival which, in turn (excluding factors such as plant material selection and handling, soil moisture conditions, post-planting care, etc.), will be dictated by both the displacement activity of the flow at the time of planting and by the initial planting density.

In general terms, the denser the planting, the greater is the probability of successfully stabilising them. Stabilisation is regarded successful if a significant reduction in surface displacement is brought about. Nonetheless, a 'stabilised' earth flow can be reactivated multiple times by any number of factors (Marden *et al*. 2008a & b), mostly climate related, but the 'chance' of reactivation will be considerably less than for an earth flow in pasture (Zhang *et al*.1993).

Gullies

Canopy closure models developed to measure the effectiveness of exotic forest in stabilising gullies showed that the time required to 'shut down' gullies was strongly associated with gully size and the duration (years) since planting, and for gullies of equivalent size, the duration since planting is similar in different geological terrains (Marden *et al*. 2005, 2011).

Also, linear gullies are likely to stabilise earlier than their amphitheatre-shaped counterparts.

At the time of planting in areas of Tertiary terrain, the greatest probability of stabilising gullies 1 ha and less in size is within the first 10 years after planting; for 5–10-ha gullies not until 30 years after planting; and for gullies ~10 ha in size longer than 30-years (Marden et al. 2005, 2011).

Physical evidence that reforestation has been effective in stabilising gullies includes channel narrowing and incision as an initial response to the decrease in sediment yield. Additional indicators are the survival of forest plantings to form a closed canopy within a once active and open gully, channel incision into depositional fans emanating from them and the subsequent stabilisation of these fans.

When forests are harvested the potential for rainstorms to promote gully initiation and expansion increases, as does the capacity of streams to entrain and transport sediment and slash (Phillips et al. 2012). The simultaneous harvesting of contiguous areas of forest over consecutive years compounds the magnitude of storm-related impacts incurred both within forests and on downstream communities.

Appendix 2

The role of natural regeneration and managed reversion in transitioning from pines to a permanent indigenous cover

In the face of increasingly frequent and severe storm events, and integral to New Zealand's Climate Change Risk Assessment of sediment and slash on receiving freshwater and coastal environments (NPS FM, National Environmental Standards for Freshwater), transitioning existing areas of exotic production forest considered 'high risk' to alternative and more resilient land uses will be paramount.

However, in transitioning from one type of vegetation cover to another, the greater are the risks and uncertainties of achieving a successful erosion control outcome, the success or failure of which may depend more on the recurrence interval and magnitude of future storm events.

Options for transitioning areas identified as 'high risk' to a longer term and more sustainable protective vegetation cover include 'passive' and/or 'managed' land use change, using pine forests a s a nurse crop and establishment of a continuous forest cover.

Table 1: Passive versus active land use change.

Passive land use change:	**Active** land use change:
• Transition is by natural reversion of indigenous species. • Generally, no planting involved – but supplementary planting may be necessary. • Will require weed, wildling pines and feral animal control.	• Transition is managed. • Requires the planting of alternative – exotic/indigenous timber species, e.g., Mānuka for honey. • Will require weed, wildling pines and feral animal control.

Passive indigenous reversion

In New Zealand, 'passive indigenous reversion' follows two main forest compositional pathways, either mānuka/kānuka shrubland or broadleaved species (Williams 1983; Wilson 1994).

Successful recolonisation of forest 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 (Moles & Drake 1999; Overdyck & Clarkson 2012), wind and a resident bird population (Enright & Cameron 1987; Kelly & Sullivan 2010).

Once established, stand age and density have a considerable influence on the degree of protection provided by regenerating shrubland against the initiation of shallow landslides. Supportive evidence includes the finding that by the age of 8 years, closed canopy stands of mānuka and kānuka provide a level of protection equally as effective as mature stands of exotic and indigenous forest in reducing the incidence of shallow landslides (Marden & Rowan 1993, Bergin et al. 1995; Ekanayake et al. 1997) and within 10-years, storm-initiated landslide damage was estimated to be 65% less than that sustained by pasture and 90% less in 20-year-old stands (Bergin et al. 1993, 1995).

A significant drawback, however, is that it would take twice as long (~16 years) and require an average stand density of ~13 000 stems/ha (Bergin et al. 1995) before their root systems would afford a comparable improvement in slope stability to that of *P. radiata* (Watson & O'Loughlin 1985; Ekanayake et al.1997; Watson et al. 1994, 1999; Watson & Marden 2004).

The lack of site-specific information on the diversity and density, and growth rates of naturally reverting species endemic to this region precludes any estimate of the time required for vegetation to establish to a stage where it could ameliorate the occurrence of shallow landslides during the post-harvest period. For some cutover areas designated as 'high risk' to further landslide occurrence, the loss of soil from areas of bare exposed bedrock will greatly slow the rate of development of a dense ground cover which is likely to be long to very long-term, perhaps several decades.

Weed competition and wilding pines are major factors that inhibit the rate of native regeneration (Lambie et al. 2020; Marlborough District Council et al. 2016). Costs for herbicide ranged between $300 and $500 per hectare (Shaw 2019; Marlborough District Council et al. 2016; Forest Lifeforce Restoration Trust 2019). A range of approaches have been used with various levels of success (Lambie et al. 2020). Most strategies have involved different combinations, strengths, methods and timing of herbicide applications to control weeds (Lambie et al. 2020; Marlborough District Council et al. 2016).

Spraying wilding exotics limits the diversity and density of germinating indigenous species (S Strang, pers. comm.) and delays the reversion process by several years. Failure to spray results in a major, long term wilding management problem.

Sustained browsing by feral and domestic animals (Wallis 1966; James 1969) also have 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 re-establishing slope stability.

Managed Reversion to a Permanent Indigenous Shrubland Cover

Forefront of options proposed for transitioning short-rotation plantation forestry in steep terrain to a permanent indigenous shrubland has been the planting of mānuka seedlings. Most of the plantings to date have been for honey production and generally established on low producing, steep, pastoral hill country impacted by storm-initiated shallow landslides.

The following is a summary of research findings on the growth rates of plantation-style (planted at fixed spacings) and naturally reverted stands of mānuka and their potential effectiveness in restoring slope stability in areas at considerable risk to the initiation of landslides.

Thus, differences in the availability of nutrients and water, together with contrasting site factors (e.g. location in the landscape, sheltered versus exposed sites, soil depth to bedrock etc.) and variable planting spacing likely explains much of the variation in mānuka growth form across the different landforms (Marden et al. 2020).

Where the soil profile was sufficiently deep, mānuka plantings had access to soil moisture and nutrients allowing for greater and earlier rates of canopy and root development. In contrast, for mānuka planted on predominantly steeper, landslide-impacted slopes, the potential for root development was limited by shallow, skeletal soils with limited potential to retain soil moisture during lengthy dry spells. Typically, and as a response to the harsh site conditions, root systems were more compact and tended to be dominated by smaller diameter roots to form a dense network, particularly of fibrous roots.

In addition, impenetrable bedrock at shallow depths further restricted root development, particularly of vertical roots. Therefore, the overall growth performance of mānuka plantings on slopes impacted by landslides was significantly less than of plantings of equivalent age established on sites with better soil coverage.

As for all plant species, a developing canopy influences the soil moisture regime largely through interception, evaporation and transpiration, thereby having some potential for reducing landslide initiation. A delay in the timing of canopy closure will reduce the effectiveness of interception loss at times when soil moisture levels are most likely to reach saturation and slopes are at greatest risk of failing.

For mānuka plantings, factors influencing the timing of canopy closure include:

- low and variable stocking density at the time of establishment
- high rates of plant mortality and slow growth rates of plantings associated with landslide-prone slopes, a consequence of factors related to site differences, including thin and nutrient-poor soils and/or poor soil-moisture retention.
- differences in canopy form/shape, related to seed source genetics and/or the ratio of single-stemmed to multiple-stemmed plants, with multiple-stemmed plants having a bushier and denser canopy than the narrower canopy of single-stemmed plants
- windthrow
- stem snap
- borer damage causing the collapse of tightly packed, multi-stemmed plants (Marden & Lambie 2019), mortality due to mānuka blight caused by the scale insect *Eriococcus orariensis* Hoy and its accompanying sooty mould *Capnodium walteri Saccardo*. In drier areas, such as the East Coast region, manuka blight generally appears 3–5 years after planting and
- myrtle rust may affect the survival of mānuka, however information on myrtle rust within the New Zealand context is lacking (Lambie et al. 2018).

Based on Hawke's Bay research, mānuka planted at an even spacing of 3×3 m (1111 stems ha^{-1}), canopy closure on landslide-affected slopes would not likely occur until 9.5 years after planting, occur earlier on stable ridge-line interfluves within 8 years, and occur earliest on colluvial slopes within about 6.5 years where soils were thickest and more fertile.

At these low densities, plantings likely remain susceptible to landslide-related damage for at least 10 years. Intuitively the higher the planting density the sooner canopy closure and root occupancy are likely to provide protection against landslide occurrence (Marden et al. 2020).

In contrast, naturally reverted stands of kānuka/mānuka shrubland where the stem density is at least an order of magnitude greater (Hicks 1991; Marden & Rowan 1993; Bergin et al. 1995) afford a higher level of protection against the initiation of shallow landslides within 8 years (Ekanayake et al. 1997).

Supportive evidence includes the finding that closed canopy shrublands (predominantly mānuka and kānuka), although of unknown age, were equally as effective as mature exotic and indigenous forest in reducing the incidence of shallow landslide initiated during Cyclone Bola (Marden & Rowan 1993, Bergin et al. 1995).

In another plot-based growth trial where equal numbers of the best performed of 12 of the more common early colonising indigenous plant species known to recolonise pine cutover planted at 1100 ha^{-1} , it was estimated that planting would likely provide only minimal protection against the initiation of shallow landslides within 5 years, a moderate level of protection would occur by year 8 while a high level of protection was unlikely until year 16 (Marden et al. 2020).

Pine Forests as a Nurse Crop

Several recently published papers offer insights on opportunities and limitations of using exotic pine as a facilitative nurse crop for New Zealand indigenous forest restoration (Lambie et al. 2020, 2021), whereby indigenous forests emerge as the exotics reach the end of their lifespans and fall over. The outcomes of such approaches are likely spurious and unreliable, may not work, and carry with them many risks and concerns about how commitments made now can be assured over longer periods – likely more than 80 years.

Continuous Cover Forest

The re-purposing of areas of production pine to a more permanent vegetation cover (e.g. single, or multiple alternative exotics and/or indigenous timber species with longer growing cycles) will not eliminate the possibility of future landslides.

Both exotic and indigenous forests are subject to sudden shocks – including storm events and fire risk – as well as the slower onset events including drought, disease and pest incursions. Nonetheless, the expectation is that the erosion susceptibility of these areas and the potential for sediment and any residual slash left behind to be mobilised during future storms would decrease over time.

Where technically and economically feasible, transitioning to a continuous forest cover offers the opportunity to continue forest production through selective harvesting or small coupe felling without undue negative impacts of significant sedimentation and slash on downstream environments and communities. The design of coupe sizes, their spatial separation and proportion of a catchment permitted to be clear felled will require consideration of the physical attributes of the terrain (slope, aspect) within a coupe, its erosion 'risk,' proximity to streams and time before replacement plantings reattain canopy closure.

As shown by Phillips et al (1991) and Marden & Rowan (1995) the greatest protection against landslide initiation following afforestation is when stands attain canopy closure.

Studies of the densities of storm-initiated landslide across different vegetation types show that there is slight difference in the protective value between different closed-canopy evergreen forest species, but that forest age has a significant effect in mitigating landslide occurrence. This is consistent with process-based research that shows there is slight difference in the magnitude of interception loss, as a percentage of rainfall, across different, closed-canopy vegetation communities (Rowe et al. 1999) thus changes in stream peak flow following afforestation also coincide with canopy closure (Davie 1996)

The concept of maintaining a continuous cover forest, in respect of which continuity of canopy cover and root structure is retained, helps preserve (rather than periodically disrupt) biodiversity habitats and improve ecosystem functionality and resilience but only in the absence of significance storms.

Species choice will have implications for a wide range of environmental effects and forest outcomes. These include longevity, stand stability, biodiversity, impacts on water yield, long-term carbon sequestration rates and volumes, soil stability, risk of windthrow, water purification and resilience to pest, disease, fire and drought, as well as broader landscape, social, reputational, cultural and economic effects.

Notwithstanding, landslides of all types have been part of the natural landscape-forming process for tens of thousands of years and irrespective of the type, maturity, density, and health of a forest terrain that is steep will always be susceptible to rain-triggered landslides, particularly so during major storms of the magnitude experienced within the past three decades.

Ministerial Inquiry on Land Use (MILU) Report Response –

Gully Watersheds Potential for Inclusion as "Purple Zones" Appendix 3:

Date: 28/06/2023

Author(s):

Malcolm Penn, Spatial intelligence

Background:

- Analysis initiated in response to following policy recommendations:

R14 *Direct officials to procure from Crown research agencies, a high-resolution soil erosion susceptibility map for Tairawhiti and Wairoa, which includes the identification of land with an extreme erosion susceptibility to create a new classification – a 'purple zone'.*

R15 *Require land with an extreme erosion susceptibility to be transitioned from current uses to permanent canopy cover such as native forest.*

R16 *Urgently focus land management policy and funding on stabilising existing gully erosion in all land uses in Tairawhiti.*

- In 2019(?) MPI commissioned a report from Mike Marden (Manaaki Whenua) and Anne Seymour on gully erosion in the Gisborne District. Included with this report is a spatial dataset of all gullies in the Gisborne District (forested and non-forested) and their associated watersheds/catchments. The basis for this spatial dataset was aerial imagery flown in 2017. This report followed two other reports by Mike and Anne on Gully erosion delivered to MPI (MAF) in 2005. These reports also included spatial datasets of gullies based on 1957 and 1997 aerial photography.

Methodology:

1. Copy of Marden/Seymour 2017 gully dataset was made and classified into three categories: < 2ha, 2 to 10ha, and >10ha.

2. A new dataset was created of buffered areas <u>around</u> the gully. The width of the buffer was based on the size classification of the gully.

Gully size class	Buffer width
<2 ha	50m
2-10 ha	100m
>10	200m

3. The gully buffer area was then intersected with the corresponding 2017 gully watershed/catchment dataset, so any land not directly connected to a gully was removed. The resulting gully buffer watershed/catchment dataset was the surrogate “purple zone” used for all further analysis.

4. Intersected the gully buffer watershed/catchment dataset (i.e. surrogate “purple zone”) with the following spatial datasets: LUM, Erosion Susceptibility Classification, LINZ property titles, Gisborne District Land Overlay 3A, Māori Land Online, to determine a basic profile of the land within the gully buffer watershed/catchment.

Assumptions:

1. Gully buffers were set at fixed distances and did not consider plantability or limiting factors to tree cover e.g. slope, soil depth, etc.
2. Land cover and gully size data based on pre-Cyclone Gabrielle imagery. Likely some figures will change with assessment using new imagery.
3. Watershed/Catchment definition: *A catchment is a basin shaped area of land, bounded by natural features such as hills or mountains from which surface and sub surface water flows into streams, rivers and wetlands. Water flows into, and collects in, the lowest areas in the landscape (Waikato Regional Council)*

Key Results:

Feature	Area (Ha)	% of Gully Buffer Area
All 2018 gullies (forested and non-forested) buffered by gully size class (50m, 100m, & 200m) then intersected with gully watershed polygons	28,726	100%
<2 ha gully watersheds (1226 features)		19%
2 to 10 ha gully watersheds (542 features)		45%
> 10 ha gully watersheds (96 features)		36%
Overlay 3A	10,956	38%
ESC layer - Red zone/Very High	21,316	74%
ESC layer - Orange zone/ High	3,145	11%
ESC layer - Yellow zone/ medium	3694	13%
ESC layer - Green zone/ Low	537	2%
LUM Native forest	6790	24%
LUM Planted P90 Forest	4420	15%
LUM Post 89 Forest	7116	25%
LUM Grassland with woody biomass	1774	6%

LUM Grassland high producing	1160	5%
LUM Grassland low producing	7345	26%
LUM Grassland (all) overlapped by ECFP established area	1133	11% (of LUM Grassland)
Maori Land Court blocks	6567	23%
Crown Land	3823	13%
Ernslaw One	3456	12%
Aratu Forest Ltd.	651	2%
Juken New Zealand Ltd.	72	0%
Summit Forest New Zealand	588	2%
Landcorp Farming Limited	234	1%

Observations:

1. Approximately ¾ of the gully buffer area already has harvest controls (i.e. ESC Red Zone).
2. Roughly 1/3 of the gully buffer area already has a permanent tree cover requirement (i.e. GDC's Land Overlay 3A)
3. Approximately ½ the gully buffer area may potentially be eligible for the ETS if afforested (i.e. LUM P89 forest and Grassland – high & low producing, woody biomass).
4. Over 60% of gully buffer area likely already has forest canopy cover (based on LUM info from 2016 imagery). *Not checked against TUR's Forest Grant data*.
5. Landownership of gully watersheds roughly 14% Crown (e.g. DOC, Landcorp), 20% large corporate Forestry companies), 23% Māori Land blocks, 43% remaining private landowners, smaller forestry investment blocks, farming incorporations etc.)

Recommendations:

1. Refinement needed of watershed boundaries using terrain modelling info from recent LiDAR and/or NIWA's REC catchment/watershed dataset.

2. Consideration/assessment needed of impact of permanent forest cover requirement in Gully watersheds (see R15) on farm/forestry viability on individual properties.

3. Intersection of gully watersheds against GDC freshwater management plans may show further overlap of restricted land use overlays.

4. Review against GDC Land Management Plan mapping to refine boundaries.

5. Review gully size classification against latest aerial imagery

6. More analysis needed to determine correlation between gullies and woody debris. Uawa catchment has fewer large gullies than other catchment yet has high incidence of woody debris downstream.

7. Review of gully dataset against latest (post cyclone Gabrielle) aerial photography with Mike Marden to reassess size and determine efficacy of Mike Marden's recommendations e.g. rotational forestry permitted in watersheds of gullies up to 10 ha.

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