Cyclone Cook Slash Investigation

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GISBORNE DISTRICT COUNCIL

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Executive Summary

Plantation forestry is a significant land use in Tairawhiti, providing for a number of environmental and economic benefits. There are, however, also a number of associated issues particularly during the harvest and post-harvest period. A key issue and the one at focus here is that of slash mobilisation events after high intensity rainstorms.

Ex-tropical Cyclone Cook struck Tairawhiti late on the 12th of April 2017. It was a relatively small storm with an average recurrence interval of between 1 and 8 years depending on location. The duration of peak rainfall intensities was a key driver during the event with rainfall of 80mm+ over a 3 hour duration causing woody debris to mobilise. The area of maximum rainfall was in the headwaters of the Uawa and Waiapu Catchments. The impacts of the storm were exacerbated by the antecedent rainfall conditions with Cyclone Debbie occurring just over a week earlier.

The only significant floods reported in the media were in the headwaters of the Uawa catchment. Firstly, the flooding in the Mangatokaru which resulted in a family evacuating, and secondly the build up of slash at Wigan Bridge in the Mangaheia. Smaller, but still significant events occurred in the Whakoau River and in the lower Waimata River. The other events in the Whatatutu and Hangaroa rivers were minor.

Only two major debris flows occurred; the Doonholm Landslide on the Tauwhareparae Road, and at “Waterfall Creek” in the Mangatokerau. Smaller debris flows and landslides occurred in a number of locations but only the Waterfall Creek debris flow generated significant slash, and produced much of the slash that migrated downstream. In the absence of widespread debris flows; tracing the slash back to the source was a more complex task than would otherwise have been the case.

The Waterfall Creek debris flow was generated at a landing on Spenser Road and there were several other landings that showed signs of edge collapse in the vicinity. Another area where landings were an issue is where they were placed close to river level making them vulnerable to flooding. Storing of slash on floodplains is also common and in a number of instances these have resulted in mobilisation from flood waters.

It was found that while not regionally extensive or numerous, those relatively small landslides that did occur were frequently associated with forestry roads. This is exemplified by extensive slipping associated with an access track cut in steep land in a west-facing slope in a side creek of Manganui Stream in the Mangatokerau sub-catchment.

Also observed in the Mangatokerau were extensive earthworks associated with new landing development in confined valleys at river level. These earthworks are characterised by lack of separation between the batter and the adjacent stream, the lack of buttressing to prevent slope failure, and the absence of silt traps or fences to stop migration of sediment from the earthworks to the waterway.

A key finding of this investigation is that we now have empirical data on the types of material involved in these events. Deconstruction of the slash piles at Wigan, log counts upstream of Wigan, and the plot counts on Tolaga Bay Beach established the dominant role of pine in the woody debris mobilised by Cyclone Cook. This finding is important since it is oft-repeated that the material is "largely willow". This is not to say that willow did not contribute, since 30% of the debris was willow or poplar at Wigan and 32% on Tolaga Beach. The willows above Wigan had been poisoned but not removed. This means that they are vulnerable during flood events.

Of the nearly two thirds of material that was pine, it was found that the largest proportion of all pine were weathered or abraded logs without root balls at one end (67% of all pine). Assessment of this suite of logs indicates that these were originally cut logs and a number were observed with waratah marks. Equally significant was the finding that a small but notable proportion of the pine logs observed at Wigan were freshly cut logs. These comprised 8% of all pine. Windthrow pine was less abundant at 6% of all pine. Similarly, cut logs were observed on Tolaga Beach and at Whakaou Stream.

The presence of these fresh cut logs is problematic. They occurred not just at Wigan Bridge, but also in the Whakoau and in Waterfall Creek. The observations at Willowbank where cut logs were used to corduroy the approaches to a ford, could suggest that this is the source of the fresh cut logs at Wigan. On the other hand, the number of fresh cut logs counted at Wigan as well on the banks upstream is significantly greater than those lost out of the ford at Willowbank. Even if it is assumed that additional logs were supplied from the pile stored on the side of the river at Willowbank the number counted at and above Wigan still exceeds that possible from a Willowbank source. The use of corduroy logs in the approaches to fords in catchments vulnerable to flood events is not ideal and more durable materials should be used instead.

While anecdotal feedback indicates that some of the logs were sourced from a landing where a load was stacked ready to ship out, no reports of such a load being lost were provided to Council. Equally, the occurrence of similarly cut logs in the Managatokerau and at Whakoau indicates a broader issue with the loss of merchantable logs during Cyclone Cook.

Gullies and flood plains with accumulations of pine slash were ubiquitous in all forests. Such slash accumulations were particularly evident in Tapuae Stream, the Mangatokerau sub catchment, and the Whakoau.

A key finding of this study is the degree to which woody debris becomes distributed within the catchments outside the forest boundary. Such slash is obvious where it has been pulled from rivers at locations such as Wigan but concentrations of woody debris is present elsewhere but is less visible. Traverses of the Mangaheia River, in particular, demonstrated that considerable woody debris; largely abraded and weathered pine logs, remained in the river system at flood height level. This material will mobilise in any future significant weather event. By implication, a slash event may occur without any debris flows occurring within a forest, because the flood levels required to move this material may be less than that needed to trigger a significant debris flow.

A considerable volume of the woody debris observed below Wigan during the over flight was caught up within the river rather than at flood height. This material is considered to be material released from the bridge during slash removal operations following Cyclone Cook. This material was flushed out of the river during a small flood that followed the over flight and ultimately ended up on Tolaga Beach.

The slash catchers in the area of highest intensity rainfall during Cyclone Cook either failed, were damaged and/or overtopped or were bypassed. The replacement slash catcher at Whakoau is already accumulating significant woody debris while a slash catcher in the Mangatoitoi is holding some slash despite there being no major floods since Cyclone Cook. This indicates that the clearing of slash catchers needs to be a regular maintenance activity within catchments. The bypass and over-topping of catchers raises questions about the effectiveness of slash catchers as a tool for mitigating against the migration of slash out of forest catchments. Further, the placement and scale of catchers such as the one at Whakoau means that they are unlikely to be effective during an event of the size of Cyclone Cook or larger.

The investigations shows that standing vegetation on flood plains and river margins can be effective in catching slash in some circumstances. The long-term effectiveness of this needs to be assessed as it's possible that larger events will mobilise these slash piles and damage the vegetation within the riparian margins.

While slash was extensively observed in the Uawa Catchment, no slash was reported in the Mata River downstream of the Whakoau River despite enough slash being mobilised to overwhelm the slash catcher. Subsequent investigations showed that pine debris reached the bridge over the Mata at Ihungia but no new material was observed on river banks at Ruatoria or at the river mouth.

Conclusions

The Event

1. Significant cyclonic events such as Cyclone Cook do not uniformly impact on the region. The location of debris flows and slash mobilisation during the weather system is dependent on the cyclone track and complex topographic variations.

2. The impact of Cyclone Cook was exacerbated by Cyclone Debbie which hit the region a week earlier and left soils saturated and led to greater runoff.

3. The available GDC weather monitoring sites do not have sufficient spatial coverage for analysis of extreme weather events. Forestry company weather stations do not necessarily record data at a reproducible level and the resultant analysis of weather data has to be treated with caution.

4. It is speculated and requires testing, that the Raukumara Ranges causes complex localised weather systems to develop which impacts on the spatial distribution of slash events. Further research would help focus attention on the most vulnerable areas.

The Impacts

5. Forestry slash effects occur during extreme storm events. The resultant debris flows and landsliding can cause or contribute to forestry slash events but as Cyclone Cook has shown, slash mobilisation and silt deposition can occur without debris flows or landslides significantly contributing to the event.

6. Slash in our rivers and reaching our beaches as well as the transfer of soil and silt to the river system during such events has amenity impacts as well as on aquatic systems and water quality.

The Assessment

7. The predominance of pine-based slash was established at multiple sites (70% at Wigan Bridge, 68% at Tolaga Beach) with this comprising mainly abraded weathered logs lost from stored slash piles or elsewhere within the forest boundaries.

8. A key finding of this investigation is the presence of a suite of logs within vunerable catchments that have been resident within the flood plain for a considerable period of time as a result of previous storm-induced slash mobilisation events. It is also clear that at least some of these long resident logs were originally cut merchantable logs and thus had an economic cost to the forestry companies.

9. This suite of logs is prone to remobilisation during high flow events but this makes an analysis of the original slash source difficult. We could identify that much material was mobilised within the catchment but it was only possible to trace slash back to a specific debris flow in Waterfall Creek.

10. Post-Cyclone Cook, a new population of forestry debris has became resident within the flood plains of several catchments. In future events this will be enough to cause risk for built structures necessary for community resilience.

11. The predominance of cut logs in Waterfall Creek (Mangatokerau) and the presence of fresh cut logs at Wigan Bridge and Whakoau indicates that merchantable logs are being caught up in these slash events. This indicates that the Cyclone Cook event represented a direct economic loss to forestry companies. Windthrow pine was present but minor.

12. In the Mangaheia Catchment, woody debris could be traced back to Willowbank Forest, and to the Managatoitoi and Mangateao tributaries, but Doonholm Landslide further upstream from the Managteao did not contribute woody debris.

13. The debris flow above Waterfall Creek in the Mangatokerau was the only significant landslide event that resulted in forestry slash being deposited on the flood plain.

14. A inspection of the overall Mangatokerau Catchment revealed that there were multiple sources of slash upstream of Waterfall Creek, including upstream of Staircase Road and from Te Kokokakahi Stream (where a slash catcher was destroyed by the event).

Forestry operations not aligned with best practice

15. Additionally, both the post-event helicopter flight and on ground inspections indicated that forestry operations had resulted in slash being retained in locations vulnerable to mobilisation by high stream flows. Slash piles was routinely stored on flood plains and slash was ubiquitous in gullies and would be mobilised be even relatively small landslide events. Slash was observed scattered throughout the river systems within forest areas.

16. Earthworks were observed adjacent to streams without suitable safeguards to stop sediment generation reaching the stream while a significant number of both landing/landing-edge failures and poorly designed forestry road/access track cuts were observed. The overall engineering standards applying to forestry infrastructure need to be assessed, and the minimum acceptable standard needs to be higher than current practice.

17. There is a reliance on mitigation measures such as slash catchers but the catchers can be ineffective with at least two instances (Whakoau and Mangatokerau) of slash catchers failing. In other instances (Mangatoitoi and Everetts road) slash catchers were overtopped or bypassed.

Willow management

18. The identification of 30% willows/poplars as a contributor to the Wigan Bridge event indicates that sources other than plantation forests contributed to the event.

19. The management tools for dealing with end-of-life willows within riparian margins needs to be reconsidered. Poisoning may kill the willows but leaves them vulnerable to failure during flood events. Such willows need to be cut down and removed.

20. Likewise, the practice of cutting logs into smaller lengths so that they can pass infrastructure such as at Wigan Bridge appears short sighted as it merely transfers the problem to the coastal zone. Further, releasing slash caught up against bridges rather than pulling it clear of the flood zone merely transfers the problem downstream.

Response and Consequence

21. A number of regional councils have adopted a set of environmental guidelines setting those minimum standards and which provide a measure against which individual operations can be assessed. Gisborne District Council does not have an equivalent guideline but one is needed.

22. Slash events impact upon the whole community and the costs are borne by ratepayers. Amenity values of our beaches and rivers is adversely impacted. Additionally, the sediment introduced from harvest and post-harvest silt mobilisation causes as yet unquantifiable biodiversity and water quality impacts.

23. Our response to such events should not involve just the ratepayers of Tairawhiti but involve council, iwi, forest owners and managers, and community stakeholders. The forestry industry is vital to the economic growth of Tairawhiti but long term sustainability requires better management of the impacts.

Recommendations

Council

1. That in the short term, Council adopt or adapt one of environmental guidelines used by other Councils and work with other councils to understand the tools and practices that have been employed to take into account issues not fully addressed in the National Environmental Standard (NES) for planation forestry. The NES provides guidance for good practice but further work is required to ensure that this good practice is implemented on the ground.

2 That comprehensive Assessments of Environmental Effects are required for all forestry harvest consents, taking into account the existing environmental values and the measures to be adopted to mitigate those effects (See schedule 3 of the NES for plantation forestry).

3 That where practicable, existing harvest consents are reviewed to ensure that the procedures within those consents are fit for the purpose of mitigating against the environmental impacts of the harvest operation and that this is measured against NES environmental guidelines (See schedule 3 of the NES for plantation forestry).

4. That consents where existing or proposed landings are within flood plains are reviewed to ensure that existing landings are protected from flood impacts and alternative sites are identified for proposed landing sites (See schedule 3 of the NES for plantation forestry).

5. That the effectiveness of current monitoring is reviewed and that cost-recovered compliance monitoring is undertaken on a business as usual basis (See schedule 3 of the NES for plantation forestry).

Implementation of best practice within forests

6. That permanent-semi permanent roads within forests, haulroads and tracks are designed to a standard that minimises risk of failure, with sidecasting avoided as much as practicable and where used, are protected using engineered stabilisation methods and consistent with the NES.

7. That roadway, haulroad and track watercourses are designed to mitigate against migration of sediment to waterways through the use of silt traps, settling ponds in receiving environments, bunding and silt fencing.

8 That ridge top or spur landings are placed is such a way as to eliminate risk of landing edge failure and that suitable areas are established for storing of slash in areas where the risk of mobilising slash into gullies and flood plains is minimised (Back Hauling). This is being developed for future consents.

9. That slash catchers are subject to rigorous engineering design and hydrological modeling to ensure that they can cope with realistically anticipated flood levels over the harvest and post harvest period and that existing slash catchers are regularly inspected and cleaned. Remote monitoring of slash catchers during an extreme flood would provide valuable information on the performance of the catchers and could lead to design improvements.

10. That incident reporting of any slash event resulting in the migration of slash into waterways is made mandatory.

11. That the current practice of storing slash on flood plains is discontinued, and existing areas of slash storage on flood plains are assessed by forestry companies and measures put in place to ensure that the slash is either removed or protected from mobilisation.

12. That forestry companies clear slash from watercourses in areas where slash within permanent watercourses have been identified.

13. That Gisborne District Council and the Environmental Focus Group work more closely to ensure that environmental guidelines, and procedures are fit for purpose and consistent with the NES for Plantation Forestry.

Peer review

This report was externally peer reviewed by Dr Les Basher of Landcare Research and this report incorporates his comments as appropriate. The report was also reviewed by Bridget Robertson to assess how the conclusions and recommendations aligned with the National Environmental Standard for Forestry which was released after this report was initially completed. This final version (v3.6) amends the conclusions and recommendations to account for the NES where appropriate.

Consultation

This report was provided to the forestry industry in draft for their comment and any established factual errors corrected. These were minor and have not materially changed any observations, conclusions or recommendations in the final report.

Limitations

This report compiles and analyses data acquired primarily by GDC staff after Cyclone Cook. While it is as comprehensive as possible, resources did not allow to a helicopter overflight over the entire district. Multiple field inspections were undertaken in a suite of forestrys throughout the district to obtain information. This was particularly the case in the Uawa and Mata catchments. None-the-less, the details obtained are considered to accurately reflect the impacts of the cyclone.

Glossary

This a technical report and technical terms are used. The list below provides a guideline to these terms.

Antecedent

A preceding event or an event that logically precedes another.

Average Recurrance Interval (ARI)

The **average** of the period in years of an event of a given rainfall total accumulated over a given duration. That is, there is a 20% chance of an event of this size occurring in any one year. This is the same as say it is a 1 in 5 year event.

Back Hauling

The process of removing slash and waste logs from a skid site or landing, or ground base to a suitable area for permanent storage of post-harvest recovery.

Batter

A batter is a slope that is angled back from its base. A bench is a horizontal cut in a batter designed to reduce the load on the batter slope.

Bund/berm

A built up embankment or barrier built around a feature to prevent escape of fluids.

Buttress

A **buttress** is an exterior support projecting from a wall (or batter) that is used to resist the sideways force; These can be a curtain of rock (riprap) installed at the base of a slope or batter.

Corduroy

The bed of a track or road that is formed by logs laid out across the road and typically covered by gravel.

Debris Flow
A type of landslide characterised by rapid chaotic movement of silt, debris and water down a slope.

Dross
Small diameter woody material, typically under 6cm caught up in forestry slash.

Forestry road
A permanent or semi permanent road, typically within a forest where the primary purpose is to transport logs from a landing or staging area to a public roadway.

Forestry access track
A temporary access track within a forest where the primary purpose is to haul logs out to a more permanent forestry road.

Haulroad/spur
A semi permanent road, typically within a forest where the primary purpose is to transport logs from a landing to a staging area.

Landing/Skid site
A constructed flat area where forestry harvest operations are undertaken. Timber is typically hauled up to a landing before de-barking and shipping to port.

Landslide
A general term for many types of earthmovement including slips, debris flows slides, etc. A "Mid slope failure" has been previously defined as a naturally occurring landslide not connected with forestry landings, roadways or other forestry activities but mid slope failures may result from stormwater drainage from landings and other forestry practices and such failures need to be assessed for cause.

Silt trap
A variety of means to ensure that silt doesn't transport out of an operation area. These can be drainage sumps where silt is directed to pits for subsequent clean out, or curtains of silt fabric spread across a slope to collect any silt migrating downslope

Slash
Waste woody material left behind on slopes, landings and piles after forestry operations. Dross is small diamter slash.

Sidecast
The material that is pushed over the bank when constructing a road or track.

Wharatah
A debarking machine used in the forest to remove small branches and bark from logs. It typically leaves marks on the trunk where the de barker teeth grip the log.

Windthrow/ windthrow logs
These are logs occurring within a forest or transported beyond a forest which have a rootball still attached at one end. Despite the name such logs may have resulted from several processes including' wind downblast (windthrow proper), trees knocked over during harvest operations, trees knocked over by landslides, or trees toppled from eroded riverbanks.

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1.0 Introduction

Plantation forestry is a significant land use in the Gisborne-Tairawhiti region, providing for a number of soil conservation, water quality, employment, and economic benefits. There are, however, a number of associated issues particularly during the harvest and post-harvest period (Phillips, Marden, Basher and Spencer 2016). A key issue and the one at focus here is that of harvest and post-harvest slash mobilisation events after high intensity rainstorms and the impact this has on waterways.

These events are a significant environmental issue for the region and impose infrastructural and fiscal risks to council and its assets. They are of concern to the community because of the environmental and visual impact, the sediment load in the rivers and to the industry since every merchantable log lost in a slash event is a loss of economic value. There is also the significant post-event cleanup cost.

In 2016 the Gisborne District Council engaged Landcare Research to advise on a programme to develop a monitoring system that cause landslides, debris flows and slash mobilisation. The system is in development and has three components;

Tier 1 Basic reporting of events by industry and potentially the public
Tier 2 Immediate response actions by council staff, and
Tier 3 Follow up detailed analysis.

Cyclone Cook hit on the 13th of April and occurred soon after Cyclone Debbie. Overall Tairawhiti got off relatively lightly in both events. There were, however, strong winds as well as an intense storm cell centred on the upper parts of the Uawa and Waiapu catchments that resulted in the mobilisation of forestry slash. The main areas of impact were in the Mangatokerau and Mangaheia Rivers (Uawa), and the Mata River and Whakaou Rivers (Waiapu). Smaller events occurred in the Whakatutu (upper Waipaoa), Waimata and Hangaroa Catchments. Other areas may have had forestry slash events but these were not reported to Council.

Cyclone Cook occurred before the Landcare-supplied reporting tools were fully developed but there was a systematic investigation guided by the Landcare advice. The investigation departed from the Landcare approach, however, as it soon became clear that the mechanisms assumed to be the main driver of slash mobilisation could only be locally applied to Cyclone Cook. The observation that slash mobilisation could occur without the intervention of debris flows and landsliding resulted in this investigation being broadened to consider the full mechanisms and impacts of such events.

The major infrastructural risk was associated with wood debris overloading the Wigan bridge near the junction of Tauwhareparae and Takapau Roads while in the adjacent Mangatokarau River, a dwelling was evacuated because of the threat.

The initial investigation showed that the Mangaheia and Mangatokarau catchments needed further in-depth investigation but also established that use of vehicle-based teams to undertake the inspections was time consuming and inefficient. Accordingly, a helicopter was engaged to undertake an over-flight of the worst affected areas so that the extent of forestry slash, the provenance of the material, and the areas for priority follow up could be identified rapidly.

The follow up investigation ultimately ended up being far more extensive than originally envisaged. This was because it soon became clear that the mechnisms of failure were both complex and subtle. It was, however, hoped that by undertaking a rigorous, comprehensive and evidential level investigation it would allow for a better understanding of the sources and causes of the problem.

1.1 Background

In March 1988 Cyclone Bola struck the East Coast causing widespread damage from land erosion, downstream flooding, and sediment deposition. Damage estimates exceeded $220m with half of this cost being funded by direct government relief payments and the remaining cost borne by the local council and individuals. In the aftermath of Bola, the Parliamentary Commissioner for the Environment was asked to review the effectiveness of flood mitigation policies and practices, and assess the likely effects of new policies on flood protection measures (Parliamentary Commissioner for the Environment 1994). The East Coast Forestry Project (ECFP) was then announced in July 1992 with the objective of accelerating the rate of land use change on the most erodable land to plantation forestry. The proposal was not without controversy, however, particularly the clearance of areas of regenerating indigenous vegetation for exotic forest planting (Parliamentary Commissioner for the Environment 1994).

The first plantings under the ECFP took place in 1993 with some areas such as the Wharerata Ranges already in pine plantation before Cyclone Bola. By 2016, the total area in exotic forestry comprised 141,581 ha. (Ministry for Primary Industries 2016) down from 156,400 ha. in 2011 (Ministry for Primary Industries 2011). The Ministry for Primary Industries 2016 report also provides data on the age of trees planted in Tairawhiti (*Figure 1*). This dataset has been recalculated to give the number of hectares ready for harvest based on the average age within each class multiplied by an average age to harvest of 28 years (*Figure 2*).

This suggests that there is around 24,000 ha. due for harvest now and a further 10000 ha. due by 2021. Thereafter harvest hectares grow to 18,000 ha. by 2026, 34,000 ha. by 2031 and a peak of 41,000 ha. by 2036 before dropping to 13,500 ha. by 2041. After 2041, harvest volumes are expected to again increase depending on the area harvested over the next ten years.

In part the presently high volume due for harvest now is a result of a lag of over-harvest-age trees in the system but not harvested due to capacity or economic reasons. From a policy perspective, it is obvious that there is a possible window for regulators and industry to formulate a management response to harvest pressures before harvest pressures rapidly increase by 2026. Of course, trees may be harvested outside this timeframe if logistics or local economic conditions dictate.

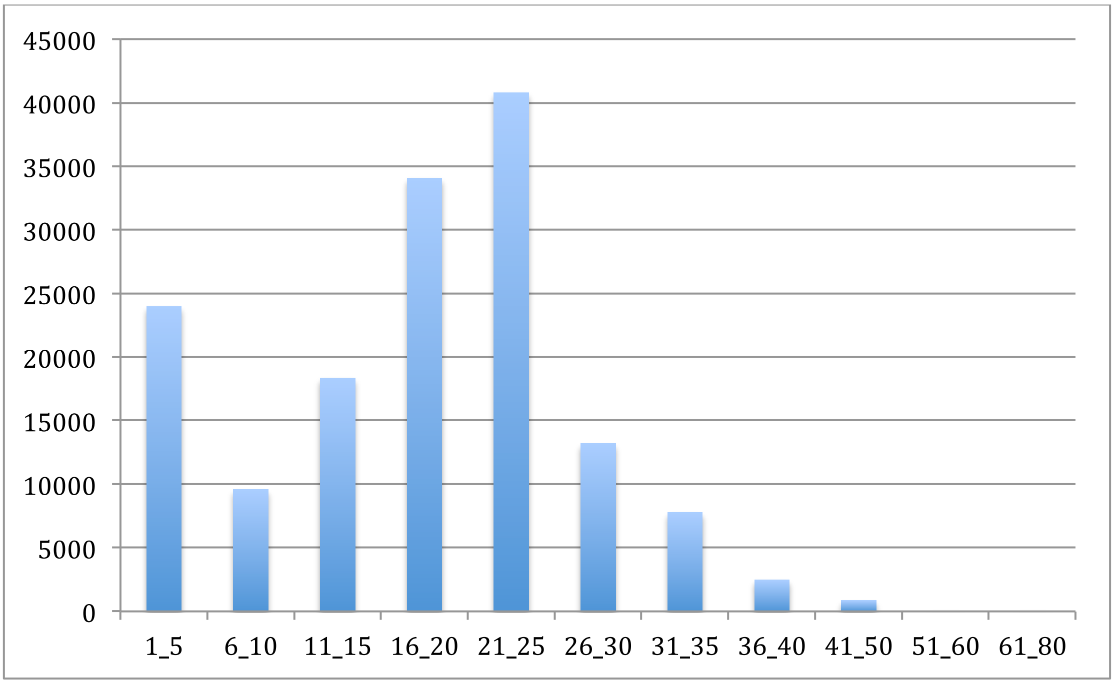

Figure 1. Age distribution of exotic plantings in Tairawhiti.

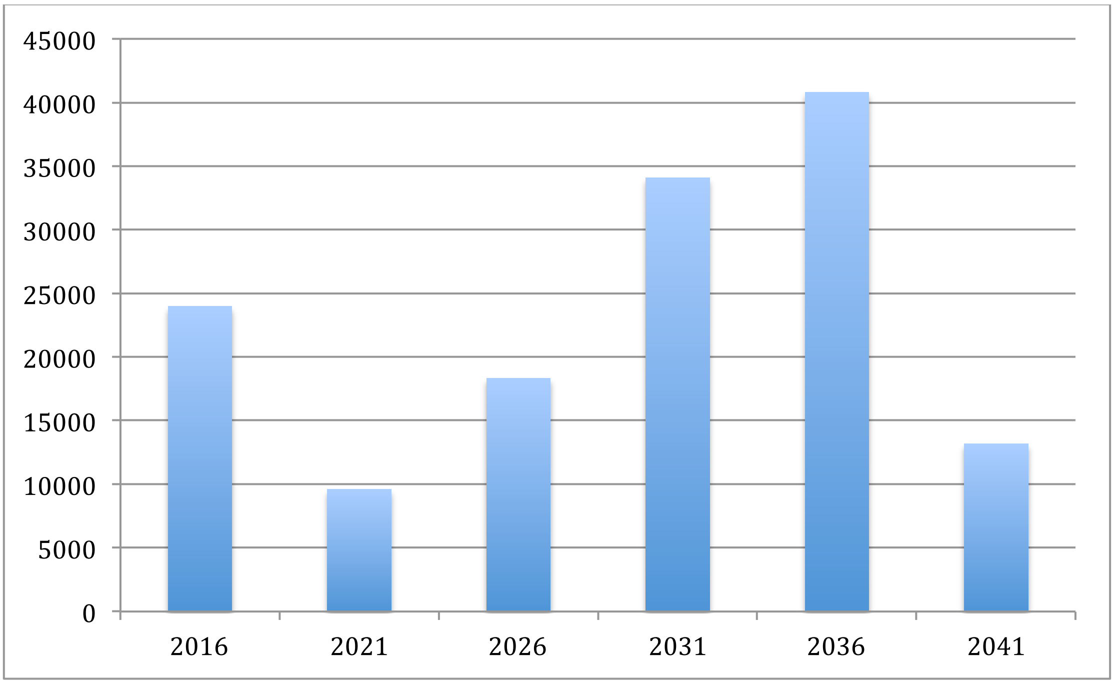

Figure 2. Plot of harvest-ready trees by hectares and years (Note that this plot excludes the c.10,000 ha of 30+year trees which are either unharvestable or for some reason not harvested at the optimum time nor does it account for trees harvested at a less optimal age for logistic or economic reasons.

1.2 Previous Slash Events

Storm-induced forestry slash events have occurred regularly in the region since 2012 and sporadically before then (*Figure 3*). It is generally considered that that forests are most vulnerable to slash events from the time of harvest to 5 to 8 years of age.

This proposition is not fully tested. It is, however, evident that based on *Table 1* there is a temporal if not causal relationship between the increase in volumes harvested and slash events during storm events.

Year	Location	Key Impacts
2015	Wharerata Forest	Major slash mobilisation, debris on beaches, sedimentation of waterways and coastal environment, destruction of farm infrastructure
2014	Inland Tologa Wharerata Ranges	Slash mobilisation, debris on beaches
2013	Tokomaru Bay	Slash mobilisation, debris on beaches
2012	Wharerata Forest	Major slash mobilisation, debris on beaches, sedimentation, loss of railway line, loss of culvert on SH2 (closing the road)
2002	Muriwai-Manutuke	Widespread flooding caused by forestry slash blocking culverts on public and private land
1994	Wharerata Forest	First major post forestry harvest event – substantial erosion and landsliding, sedimentation and slash mobilisation
Annual	Regionwide	Localised storms causing sedimentation of downstream waterways, blocking of private & public road culverts, forestry debris on local beaches

Table 1. Summary of slash events in Tairawhiti region

It seems clear from Table 1 that on average a significant event can be expected somewhere in Tairawhiti every two years but that an event might well occur in any one year based on current harvest volumes. Based on *Figure 2*, it is also clear that the risk becomes extreme in the decade between 2026 and 2036.

1.3 Protocols for monitoring and post-storm data capture

A key finding of the 2016 Landcare research was that there does not appear to be one consistent approach to gathering information that is directly relevant to storm influence and landscape response to steepland plantation forests (Phillips *et al* 2016). The research concluded that storms have the potential to cause landslides and debris flows at any stage in the forest cycle but that these are generally more likely in the 5-year period following tree harvest. It was also concluded thst it would not be possible to fully reduce the risk of post-harvest, storm-induced landslides and debris flows as the processes are a natural landscape response to major events.

Further, it was concluded that the collection of information in a consistent and methodical way for a storm event is necessary to both improve the understanding of the hazard and thus support land use planning. The key conclusion was that;

"Obtaining relevant, credible and defensible information to inform the public and to be used by GDC and the forest industry is thus a high priority" (Phillips *et al* 2016).

Figure 3. Resident viewing slash on Tolaga bay Beach 2012

Landcare Research recommended the following:

- that a database be developed to capture and store information relevant to storm events that cause landslides, debris flows, and their impacts related to plantation forestry.
- that a standardised reporting template be developed for use by both GDC and forestry companies. ,
- that a 3 tier reporting system be used, and
- that that GDC and the Environmental Forestry Group consider widening the issue to other regional councils and forestry companies.

1.4 Event Locations

The main woody debris events identified following Cyclone Cook are shown in *Figure 4* below. As this demonstrates there were no slash events **reported** north of the Mata Road. It is possible that events did occurred here but were not reported. The three main events occurred between the Mata Road and the Tauwhareparae Road, while the Waimata event was locally significant but had a lower overall impact than at the Mangaheia, Mangatokarau and Whakoau rivers. The Hangaroa event was also locally significant but smaller than the more northerly events. Only one small event in the Whatatutu was observed but there may have been other smaller events that were unreported.

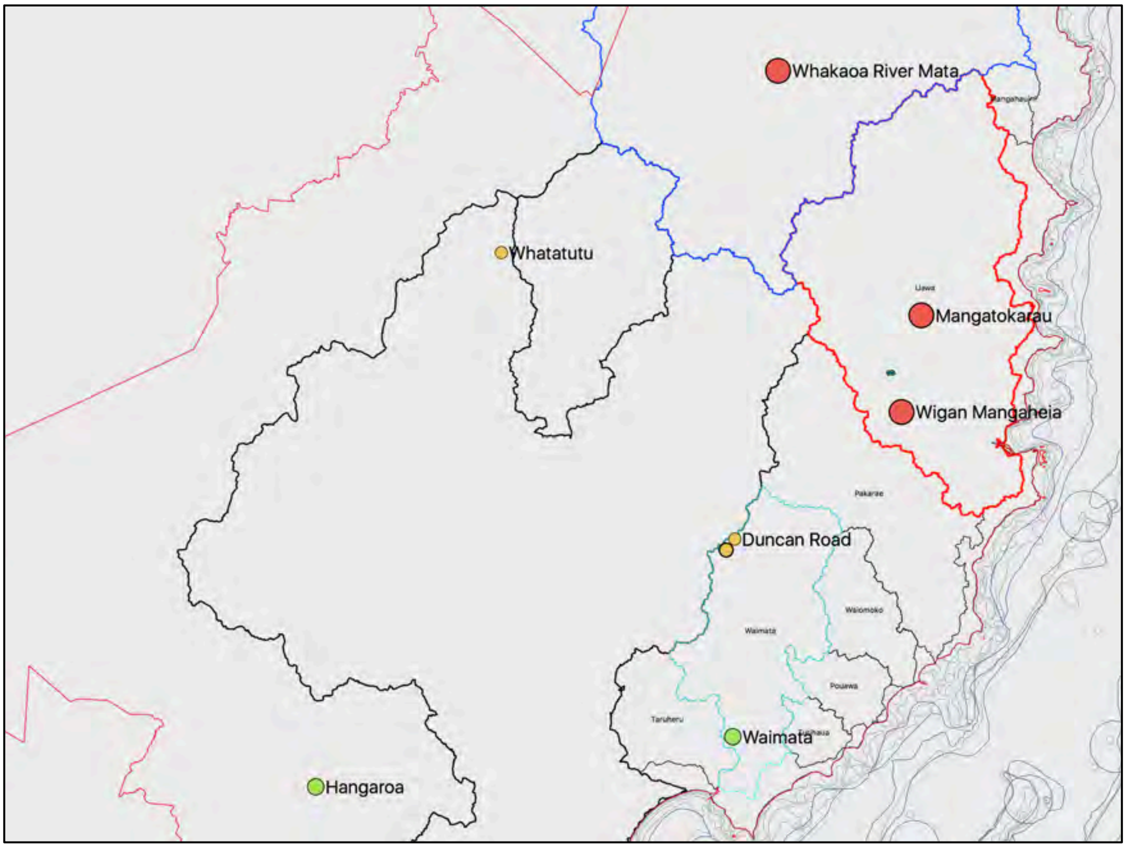

Figure 4. Location of major (red), moderate (yellow) and minor (green) slash events and catchment boundaries during Cyclone Cook.

2.0 Cyclones Debbie and Cook

Cyclone Cook was an intense weather system that struck at around 11pm on the 12th of April and had a total duration of between 24 and 30 hours with the last rainfall occurring at 5am on the 14th April at the Oweka Rain gauge. Contributing to the impact of Cylone Cook was Cyclone Debbie 7 days earlier. While Debbie was a smaller event with a peak rainfall of 16 hours the antecedent rainfall meant that soils within the catchments were saturated and the capacity to absorb additional water was minimal (*Figure 5*).

Peak rainfall intensities occured over a period of between 3 to 9 hours in the late afternoon on the 13th of April at most monitoring sites. The duration of peak rainfall intensity appears to have been the key driver of slash mobilisation in the affected catchments (*Figure 6*). In the headwaters of the Uawa and Waiapu catchments, total event rainfalls of between 95 and 100mm occurred over the entire event and in excess of 50mm fell over 3 to 4 hours.

Cyclone Cook was not a major storm relative to other storms such as the 2015 event with average recurrence intervals (ARI) of between 1 and 8 years depending on rain gauge location and with an average ARI of 2.61 years and a mean ARI of 4.5 years (*Figure 7*). This means that there is a possibility of a similar event per year of between 22% at an ARI of 4.5 and 38% at an ARI of 2.61. The river and rainfall gauge stations used for the detailed analysis of rainfall and flood conditions are shown in *Figure 8*.

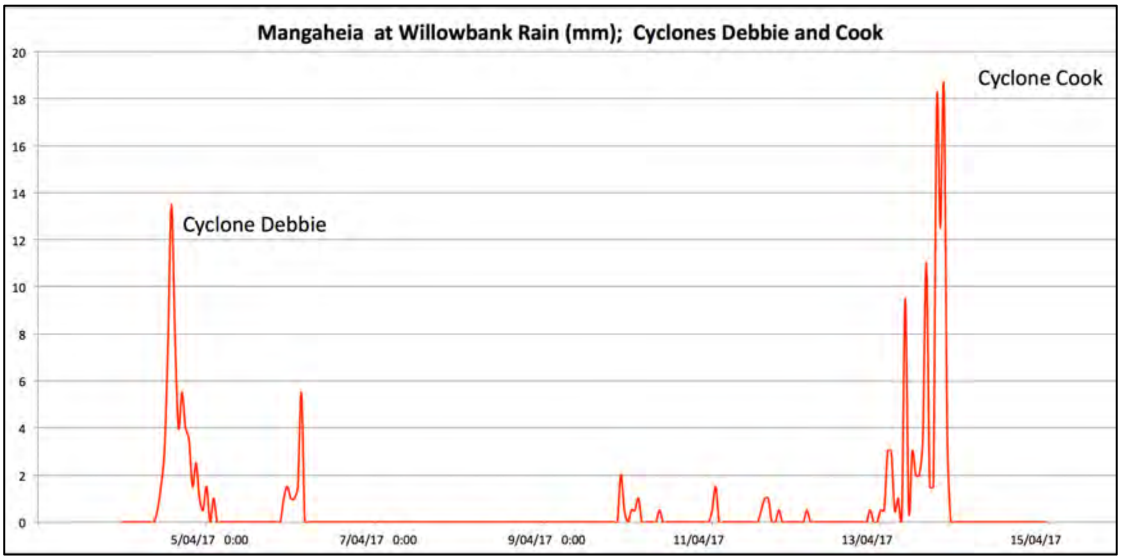

Figure 5. Comparison of hourly rainfall for Cyclone Debbie and Cyclone Cook in the Mangaheia catchment.

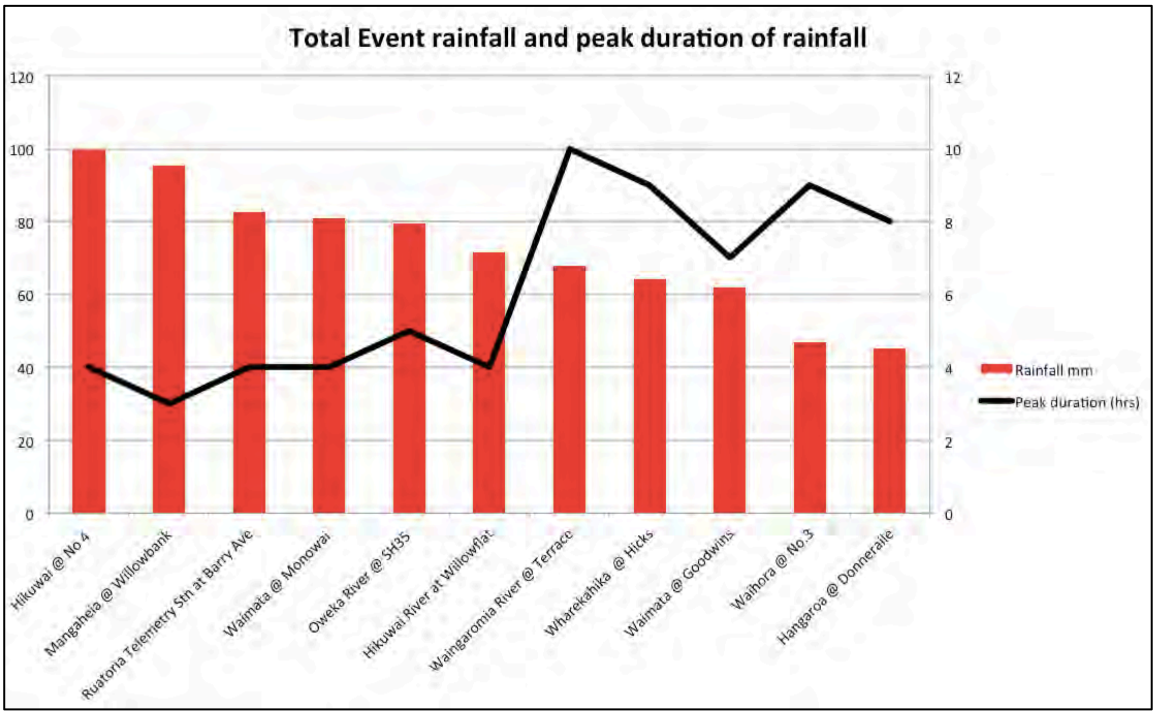

Figure 6. Total event rainfall vs peak duration of peak rainfall during Cyclone Cook.

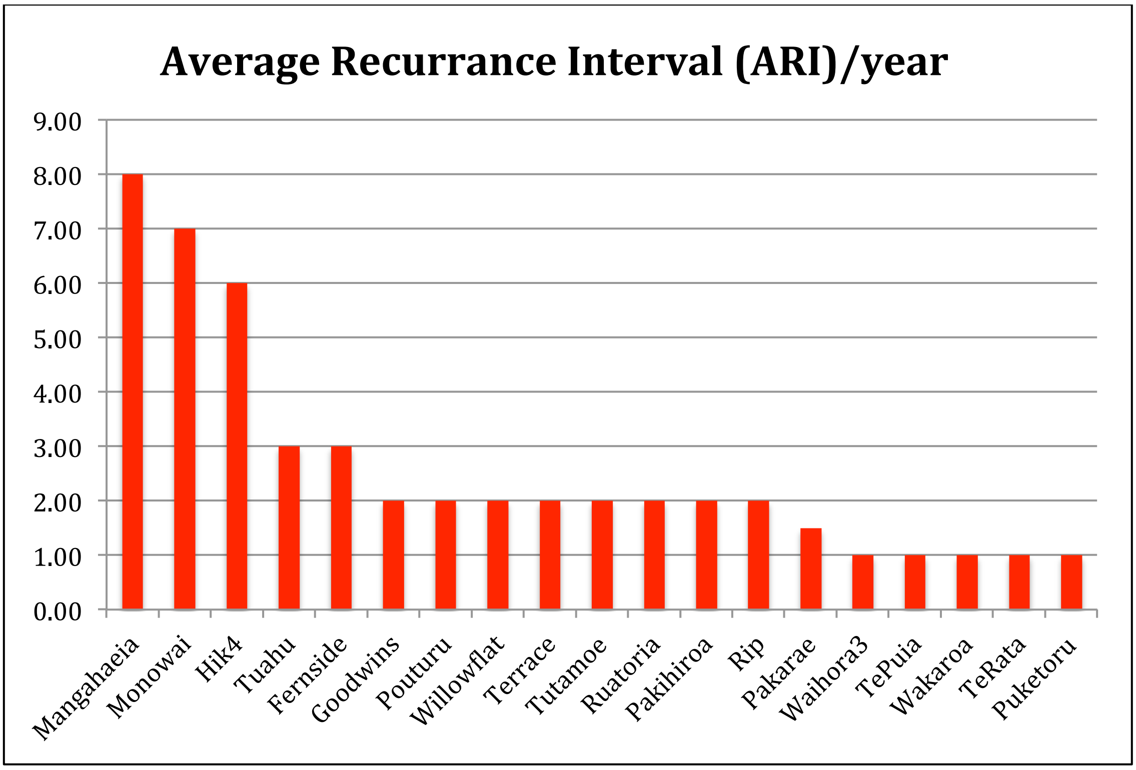

Figure 7. Average peak rainfall recurrence interval (ARI) in years for the rain gauges in this analysis.

The rainfall distribution for Cyclone Cook has been modelled using the full event rainfall data from all reliable rain gauges (*Figure 9*). This indicates that the peak rainfall event occurred in the headwaters of the Uawa and Waiapu catchments. This is consistent with the evidence of slash mobilisation recognised in this study. While consistent, the data needs to be considered with some caution since the distribution of rain gauges is not uniform with a number of gaps. There is also a potential degree of unreliability within the data due errors in the recording of data at some gauges, for example, where high winds may have reduced accuracy.

3.0 Investigations

The Land and Soil team supported by the principal science advisor have undertaken a comprehensive assessment of the Cyclone Cook event. These investigations have fallen into 5 phases;

1. Initial rapid assessment followed by overflight,
2. Detailed catchment and site specific assessments,
3. Numerical analysis of slash deposits,
4. Desktop analysis of weather data, and
5. Review of the Landcare risk matrix and reporting framework.

The field investigations were extensive with much of the focus on the major events in the Mangaheia and Mangatokerau Catchments (*Table 2*).

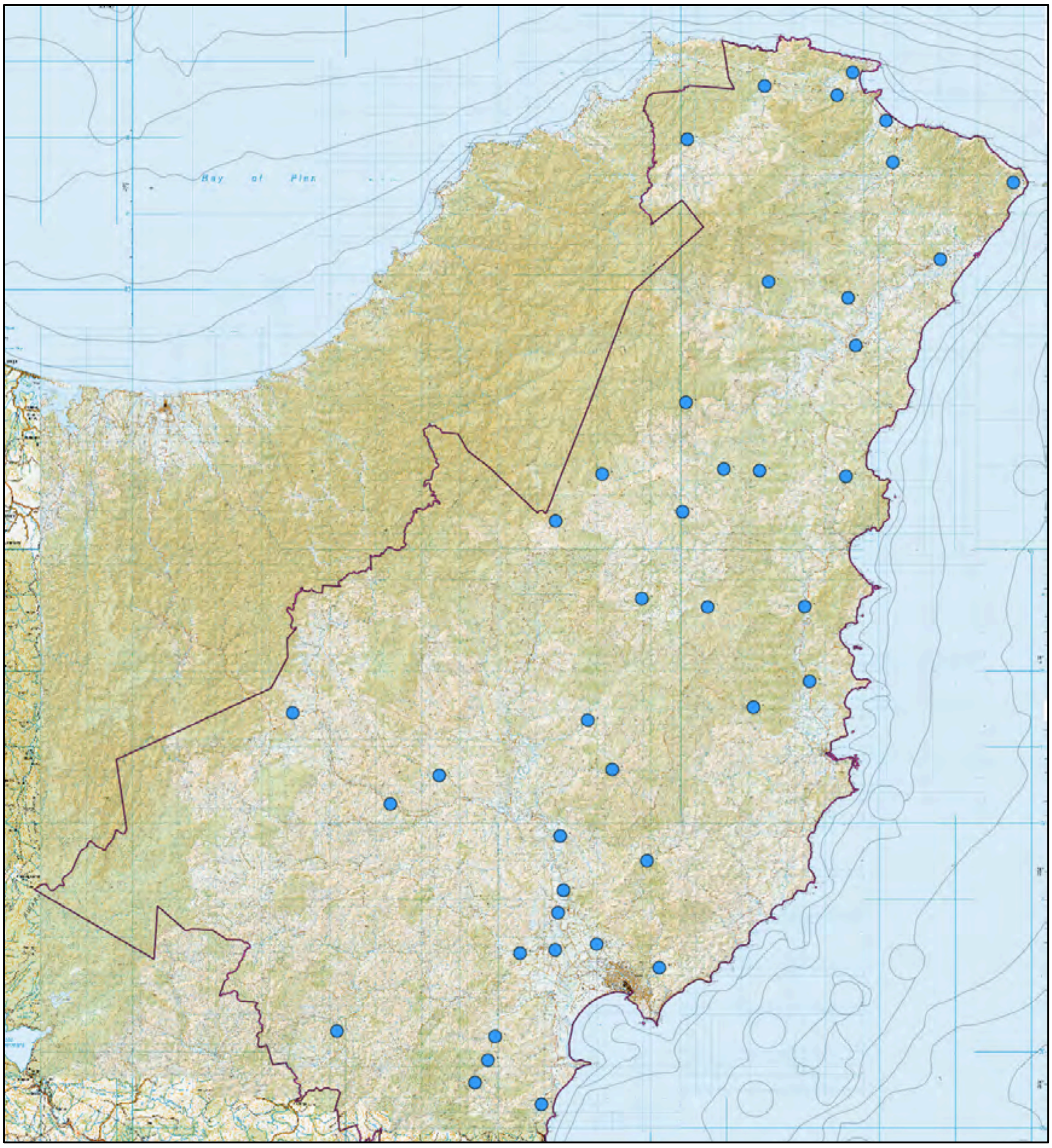

Figure 8. Distribution of GDC rain gauges used in analysing Cyclone Cook.

3.1 Initial Rapid Assessment

Because Cyclone Cook occurred at the beginning of Easter when all staff were on holiday, the earliest date that the rapid assessment could be undertaken was the 18th of April. Newspaper reports (*Gisborne Herald 15th April 2017*) indicated that the storm was centred north of Gisborne. A request for photographs from the paper indicated, however, that no photographs related to any woody debris events were taken by the paper. The newspaper reports noted;

General manager for Tairawhiti Roads Dave Hadfield said the storm caused major damage in the Mangatu and Tauwhareparae catchments……. One landslide at Doonholm at Tauwhareparae will take several days to clear and the bridge at Wigan was overtopped due to wood slash forming a dam.

"We were fortunate the event did not last for another day, as we might have lost the bridge". he said.

The Hikuwai River near Tolaga Bay rose towards trigger levels for evacuations in that area. "We were considering moving people from their homes but then fortunately the rain stopped and no one needed to be evacuated," said Gisborne District Council civil defence and emergency manager Louise Bennett……

Mrs Bennett said a family in the Tauwhareparae area evacuated when they became concerned about a build-up of debris under a bridge on their road. The Gladstone Road bridge had a small amount of debris build-up under it yesterday morning.

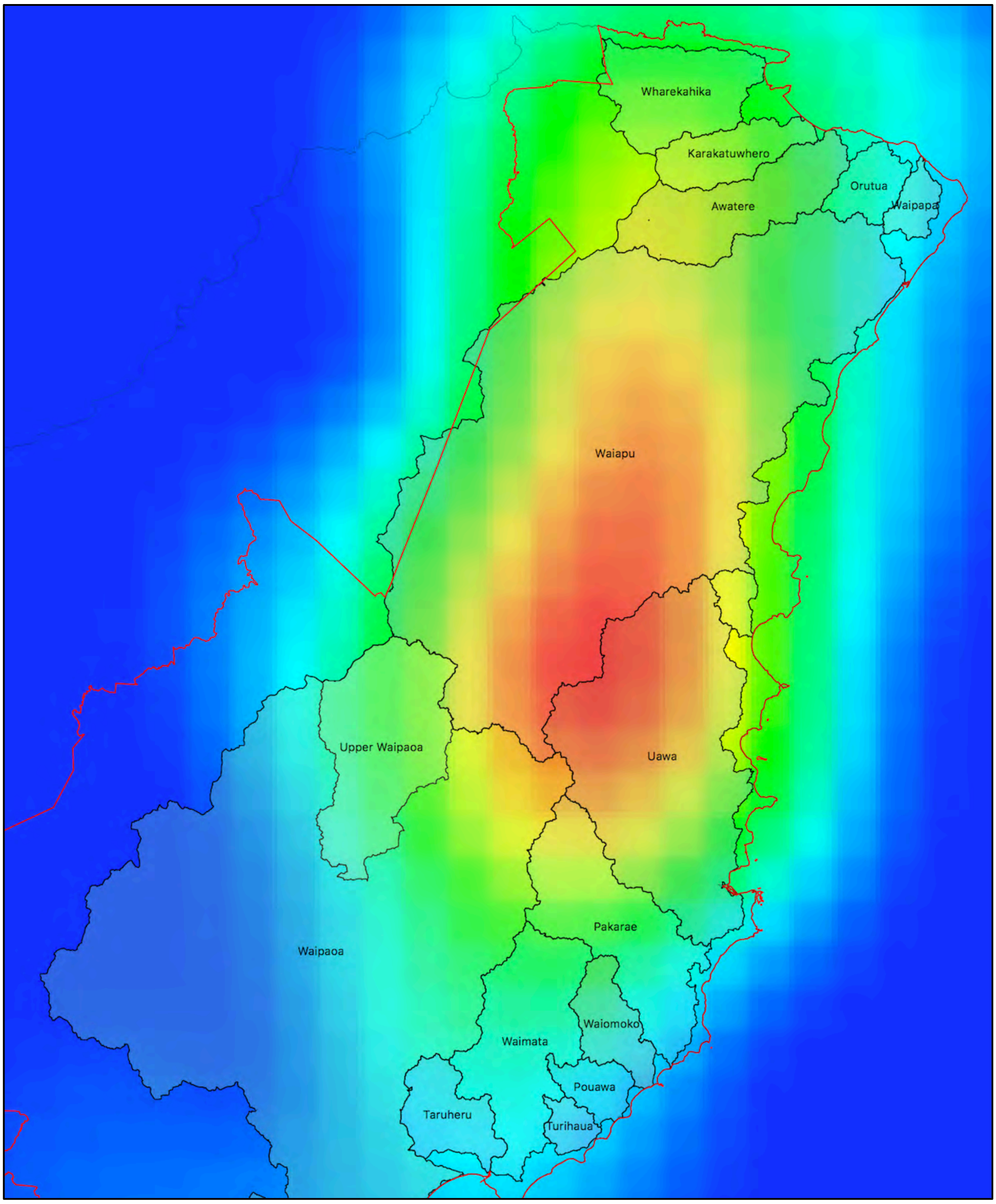

Figure 9. Kernal density map of Cyclone Cook rainfall showing the highest peak intensity rainfall (red +90mm) falling on the headwaters of the Uawa and Waiapu catchments, dropping off to the south and North East to ≥40mm (pale blue).

13th April	Regional	Cyclone Cook hit	
18th April	Regional	Initial visit Mangatokarau, Mangaheia, Wiamata, Waipaoa	ND JL MC
20th April	Waimata	Detailed Inspection	ND JL
21st April	Regional	Helicopter flight Gisborne to Mata Waipaoa headwaters	Full Team
24th April	Mata	Failed slash catcher inspection Whakoau	KH SG MC
30th April	Hangaroa	Significant willow close to bridge and on river bends	MC
13th May	Mangaheia	Doonholm, Mangatoitoi,	MC
14th May	Mangaheia	Wigan Bridge below Wigan Bridge	MC
16th May	Mangaheia	Everetts Road	KH ND MC
30th May	Mangatokarau	Assessment Staircase, Waterfall Creek, Te Kokokakahi Stm	MC
9th June	Managheia	Drone flight 5 Bridges, Everetts Road to Willow Bank	DS MC MB
12th June	Managheia	IAbove Wigan Bridge	ND, JL
14th June	Mangaheia	Tolaga Beach	MC
16th June	Managheia	Site meeting with Fulton Hogan Wigan Bridge	JL MC
17th June	Mangaheia	Upstream from Wigan Bridge to Managatoitoi	MC
25th June	Tarndale	View of slash in Whatatutu River	MC
1st July	Mangaheia	Paroa Rd Bridge	MC
4th July	Mangaheia	Deconstruction Slash Piles Wigan Bridge	MC JL
5th July	Mangaheia	Deconstruction Slash Piles Wigan Bridge	MC
11th July	Mata River	Inspection Slash Piles upstream of slash catcher Whakoau	MC
11th July	Mangaheia	Post deconstruction inspection Wigan Bridge	MC
11th July	Tolaga Beach	Photo coverage	MC
22 August	Tolaga Beach	Citizen Science project	MC, ND, SG
3 rd Sept	Mangaheia	Mangateao Stream	MC

Table 2. Field assessments undertaken as part of the Cyclone Cook slash event assessment (Initials refer to staff members).

A team followed up on the newspaper reports by travelling up the Tauwhareparae Road to the Doonholm landslide as well as the Mangatokerau Valley and the lower end of the Mata Road. On the same day, other staff carried out an inspection of the lower Waimata River, as well as the lower Waipaoa and Waikanae Beach. On the 19th of April a team undertook a follow up inspection of storm damage along Cave Road following a request for service (RFS) about storm damage from a resident *(Figure 10)*.

3.1.1 Tauwhareparae Road Inspection

The initial inspection on Tauwhareparae Road identified both the debris flow at Doonholm Landslide (*Figures 11 and 12*) and debris caught up at Wigan Bridge (*Figure 13*). Views of the river below the Doonholm landslide showed no indications of woody debris in the river but small side creeks were flowing dirty.

3.1.2 Mangatokerau Valley

The indications for a significant slash event was far more evident in the Mangatokerau with woody debris blocking the river in places, covering the river banks and slash piles on the edges of Mangatokerau Road.

The presence of significant pine was evident in many places (*Figure 14*) but there was also a considerable volume of smaller finer woody debris caught up against the river-side willows (*Figure 15*). The considerable amount of material piled up against the road indicates that the full valley floor was occupied by the flood event (*Figure*

16). As was the case with the Mangaheia, the rapid assessment did not locate any sources for the woody debris.

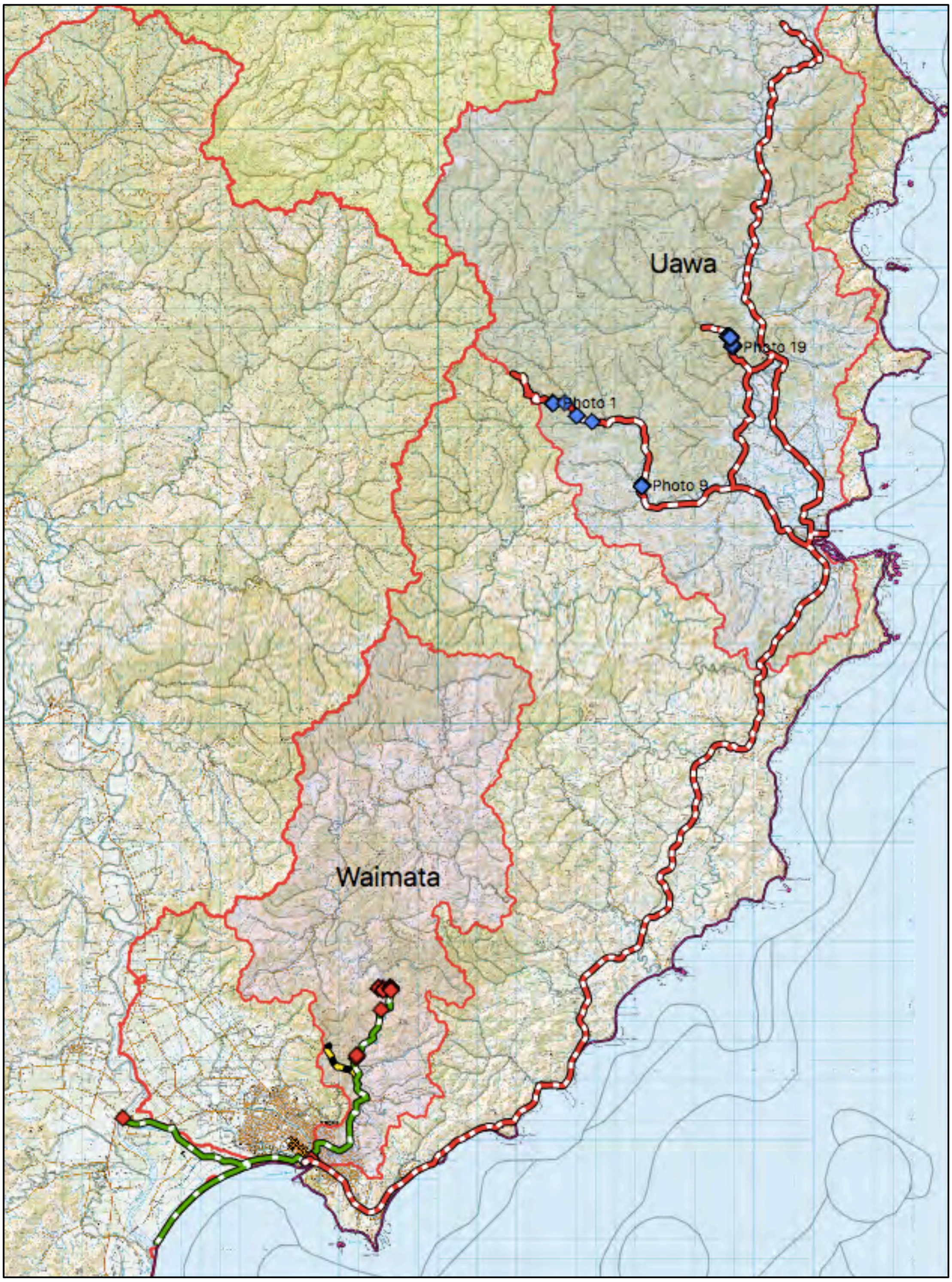

Figure 10. Map showing the routes undertaken during the initial inspection of storm damage on the 18th and 19th of April 2017. The blue and red symbols show where georeferenced photographs were taken.

Figure 11. View of Doonholm Landslide during clearing operations.

Figure 12. Photograph of Doonholm Landslide taken before work to clear the photo (Photo SSL via Tairiwhiti Roads).

Figure 13. Debris caught up against Wigan Bridge; note the presence of cut pine logs and butt ends.

Figure 14. Pine logs and finer woody dross caught up on the Mangatokerau river flats.

Figure 15. Pine logs and fine woody dross caught up against willows on the banks of the Mangatokerau River, with fresh silt deposition also evident.

Figure 16. Pine logs and dross piled up against Managtokerau Road. This debris and the flattened grass in the foreground gives a strong indication of flood height suggesting that the entire valley floor was flooded.

3.1.3 Lower Waimata River

The initial inspection of the Waimata River excluded Cave Road but followed the river valley up from Riverside Drive up to the last houses at the top of the lower valley. Examination of the river banks showed signs of significant failure of river banks (*Figure 17*) and some signs of woody debris but the volumes were not significant (*Figure 18*). Similarly, the volume of wood caught against the Gladstone Road bridge were not significant (*Figure 19*).

Figure 17. Slumping of the banks of the Waimata river after Cyclone Cook.

Figure 18. Woody debris on the banks of the Waimata River 18^th of April 2017.

Figure 19. Woody Slash lodged against the Gladstone Road Bridge in Gisborne City.

3.1.4 Cave Road

Cave Road was visited by the Land and Soil team on the 19th of April following the receipt of a request for service (RFS) from a member of the public. Significant movement of slash from a recently harvested pine plantation was identified with woody debris mobilised downslope and lodging against a fence. The fence acted to stop most of the slash from reaching Cave Road itself (*Figure 20*).

Figure 20. Forestry slash held up against a fence on Cave Road, Waimata Valley.

Examination of the slope indicated that much of the slash moved down slope by concentrated flow in gullies rather than via a generalised mobilisation of the slope during sheetflow (*Figure 21*).

Based on an analysis of the debris remaining on the slopes, it is evident that much of the movement in the gullies was due to the gullies being used as storage areas for the slash piles remaining after harvest.

Figure 21. Photo of north-facing slope above Cave Road showing slash filled gully.

3.1.5 Hangaroa

The Hangaroa River was inspected on the 30th of April immediately upstream of Hangaroa Bridge at Ellmers Road. Woody debris was observed several metres above normal flow height on the meander bend with one significant birds-nest of mainly small woody debris. Further downstream close to the bridge a number of large willows were caught up high on river banks (*Figure 22*).

Although the majority of woody debris was clearly willow, one probable pine log was also identified. As the area of plantation forest upstream has not yet been subject to wholesale harvest the overall lack of pine is not a surprise.

Figure 22. Windthrown and river-borne willow on the banks of the Hangaroa River by Ellmers Road.

3.1.6 Mangatu River (Tarndale)

The Tarndale landslide in the head reaches of the Waipaoa was visited on the 25th of June. Although the Waiapaoa catchment had not been identified as having a significant slash event, observations of the Whatatutu River tributary of the Waipaoa from Tarndale showed that forestry slash was stored on the flood plain. It was also observed that there signs that this slash had been mobilised and subsequently cleaned up into piles on the flood plain (*Figure 23*).

3.2 Post Initial Rapid Assessment Review

Following the two days of initial assessment, it was clear that to undertake a comprehensive rapid assessment over such a large area from the road would take a considerable period of time. Options to speed up the process were then considered and use of a helicopter to provide good coverage over a large area over a short period was considered the only viable readily available option.

Figure 23. View of the Mangatu River from Tarndale show slash piles located on the flood plain.

3.3 Flight design

The flight route was designed to take in the Waimata, Uawa (Mangaheia and Mangatokerau rivers), Upper Waiapu (Mata and Whakoau Rivers) and Upper Waipaoa catchments. The flight was undertaken on the 21st of April, which was the first day a helicopter was available and the weather suitable. The flight crew included Land and Soil team members and the Council's principal science advisor.

In excess of 2000 high resolution images were captured on a GPS enabled Canon 7D Mk 2 camera with a 24mm fixed focal length lens at f9, ISO 400, and a shutterspeed of 1/320th of a second. Smartphone imagery was also captured and two team members acted as spotters.

Post-flight processing involved separating out key photographs showing specific features of relevance and then exporting the geo-referenced metadata from the images as a text file. The metadata was then converted to a comma separated value file and imported into a geographic system. The flight path and specific image locations could then be plotted to aid the targeting of areas requiring more indepth post-flight investigation. Key images from the overflight are included in **Appendix One**.

The flight path is shown in *Figure 24* below.

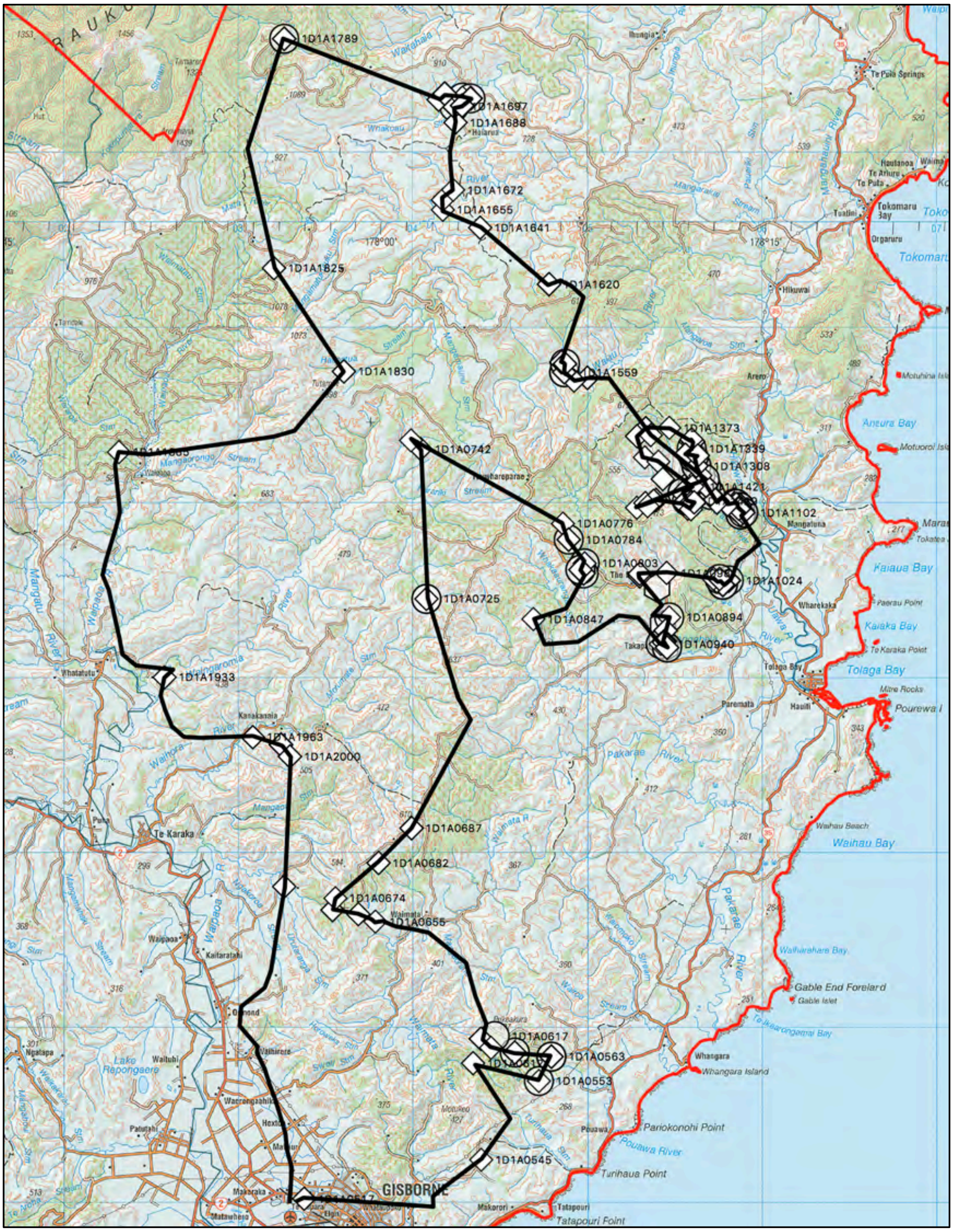

Figure 24. Plot of the flight path for the helicopter inspection undertaken on the 21st of April 2017. The diamond shapes indicate the location of key evidential images while the circles indicate the corrected position of key images.

3.4.1 Flight Segment One Waimanu Forest

Waimanu forest straddles the eastern edge of the Waimata catchment and the upper Pakarae Catchment with harvesting initiated in the eastern end of the forest in 2013. The flight path and image identifiers are shown below (*Figure 25*).

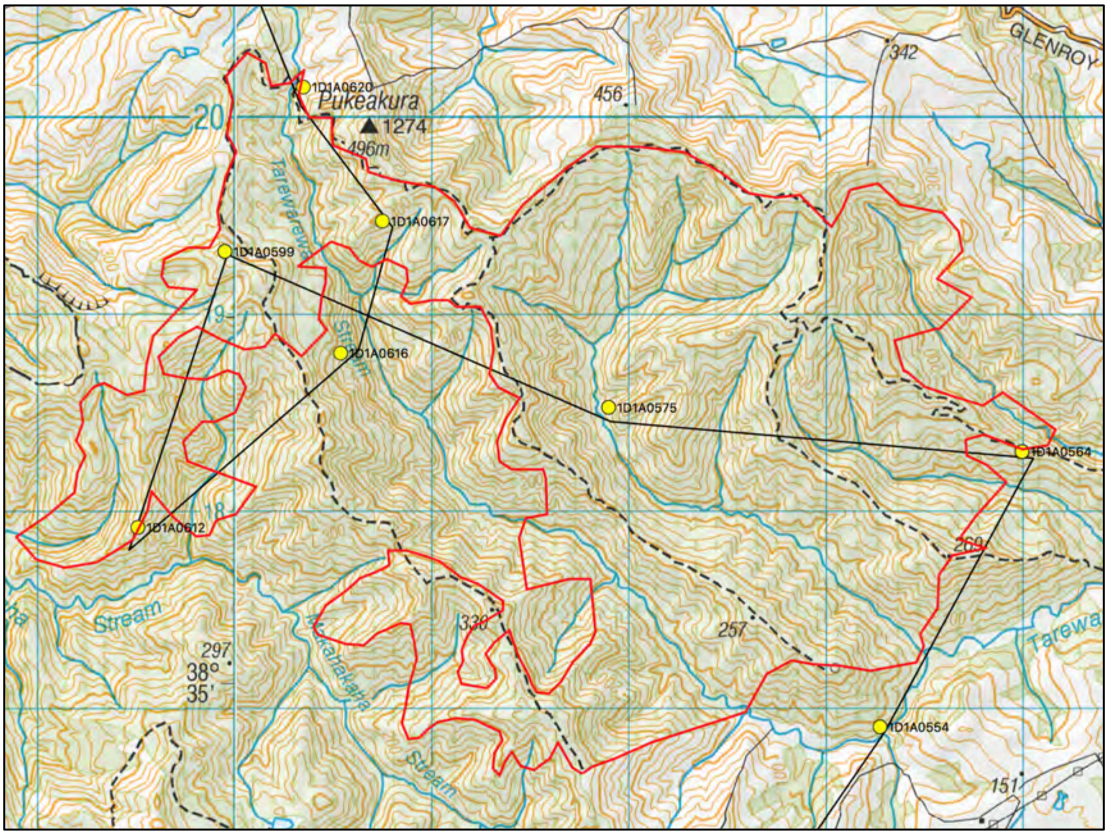

Figure 25. Waimanu forest (Eastern Waimata and, Pakarae Catchments) showing flight path, image identifiers (white) and approximate areas of harvest at the end of 2016.

This segment showed that slash had been mobilised and caught against standing pines as well as bridging the stream (image 1D1A0553. *Figure 26*). Other images of this forest did not show signs of recent slash mobilisation but did show slash located in positions adjacent to streams where they would be vulnerable to mobilisation in an event larger than Cyclone Cook. Image 1D1A06563 showed unstable road cuts and slash within the bed of Tangimatai Stream while images 1D1A0591, 1D1A0599, and 1D1A0617 showed non-windthrow logs caught in the steep freshly harvested creek bed, and slash shed off a landing. Image 1D1A0612 shows extensive slash caught in steep gullies and shed off a landing at the head of Makahakaha Stream adjacent to Pahi Stream (See **Appendix One**).

3.4.2 Flight Segment Two; Waimanu Forest to Tauwhareparae Road

North of Waimanu Forest a number of minor fresh landslides were observed (Image 1D1A0687) as well as pre-existing larger landslides (1D1A0657, 1D1A0658, 1D1A0692) (see **Appendix One**). Between Duncan and Waimata Valley Road south of Wakaroa a number of fresh landslides were observed including in replanted pines, as well as a landing failure and edge of roadway collapse (*Figure 27*).

Figure 26. View of Tarewarewa Stream showing slash piles caught in standing pine trees and logs bridging stream (far right) as well as slash piles on the flood plain and slumping (Middle left).

Figure 27. Two fresh landslides adjacent to Duncan Road, near Wakaroa.

In the Hokoroa Road area, fresh harvesting was underway in Makahakaha Ngarara Stream (*Figure 28*) and pine slash was evident caught up in the stream and adjacent to the stream in an area vulnerable to mobilisation during a major storm event (*Figure 29*).

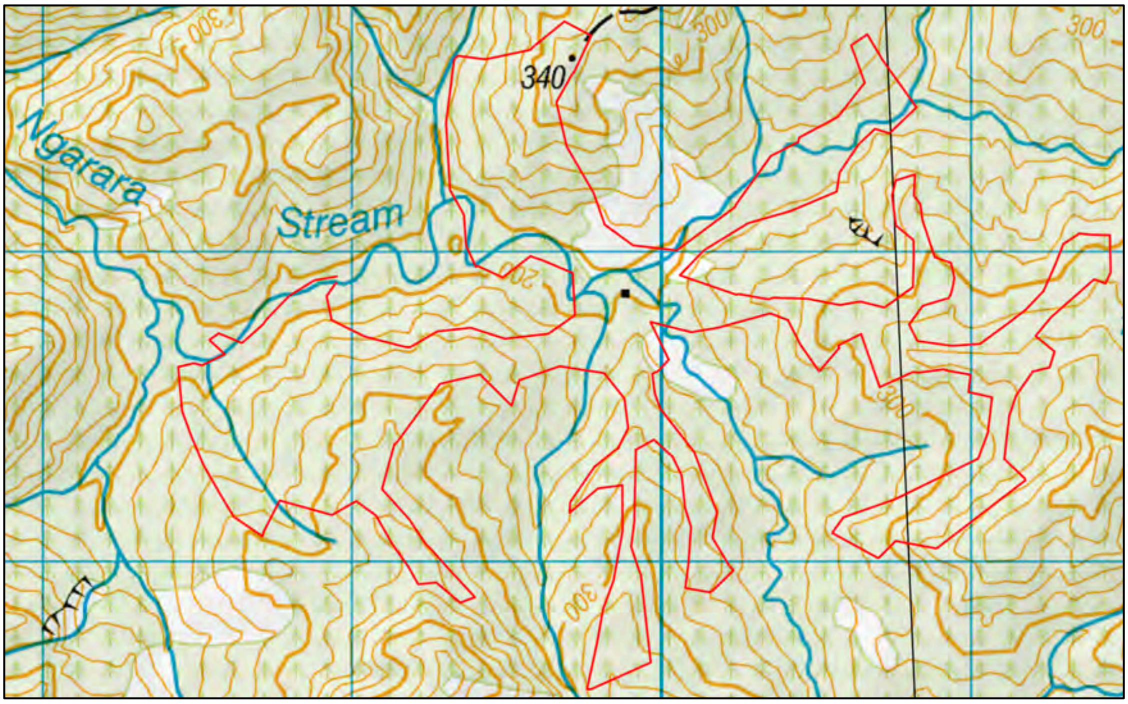

Figure 28. Harvest area in Makahakaha Ngarara Stream

Figure 29. Fresh harvest area in Makahakaha Ngarara Stream showing slash caught up in the stream (middle right) and slash stored close to the river at a site vulnerable to mobilisation.

3.4.3 Flight Segment Three; Upper Tauwhareparae Road-Doonholm Landslide

The section between Huanui Road and the Doonholm landslide was a key are of focus since the failure of the landslide and closure of the road was widely reported.

A number of smaller landslides were also evident at roadway edges and landings (*Figure 30*) and refer image 1D1A0780 **Appendix One**. A suite of images were taken of Doonholm landslide but none of these show the area below Tauwhareparae road and hence it could not be established whether or not debris from the landslide reached the Mangaheia River. The flight south west of Doonholm landslide did not show signs of significant debris flows or wood mobilisation.

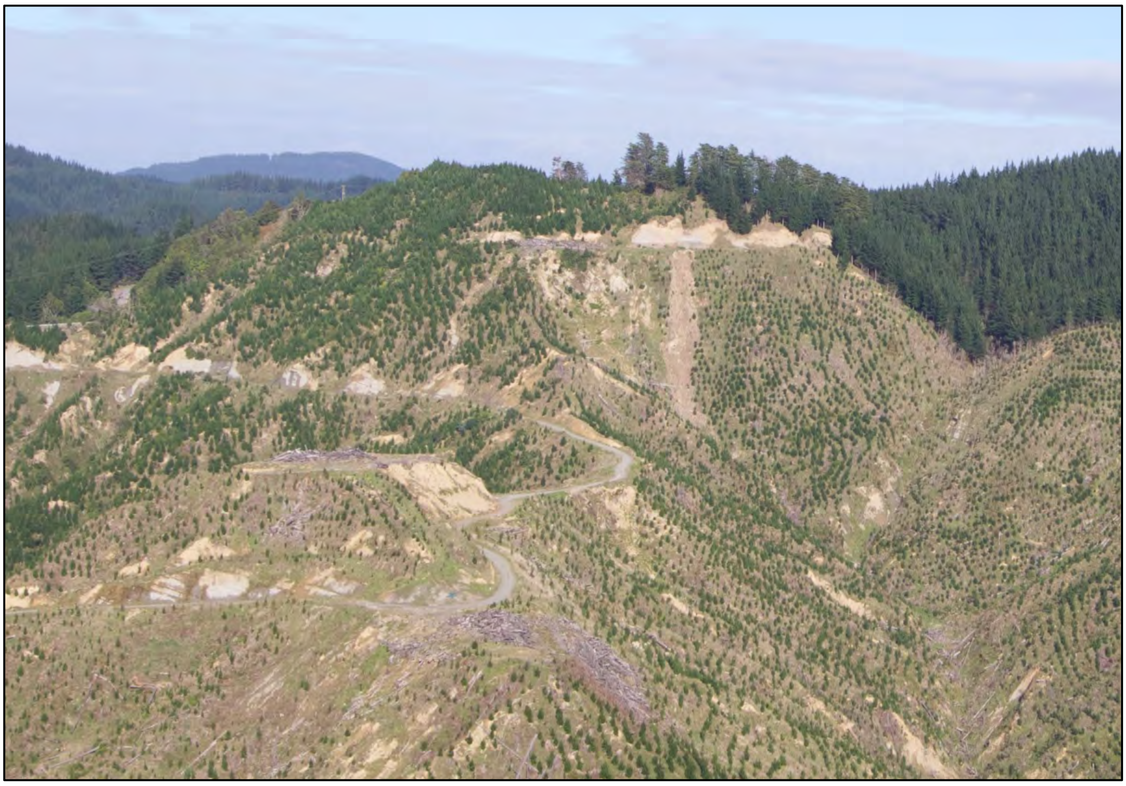

Figure 30. Landslide at the edge of a forestry road just north of the Tauwhareparae Road (middle top). Note the slash on the slope below the landing in the middle foreground

3.4.4 Flight Segment Four; Mangaheia River; Willowbank to Wigan Bridge

As Wigan Bridge on the Tauwhareparae Road was one of the sites most adversely affected by Cyclone Cook it was a key area to assess during the flight. The bridge is located on farmland with no adjacent forestry and the objective of this part of the flight was to assess both the damage and the volume of woody debris within the river. The flight path approached the Mangaheia from the west approximately 1.5km north of Wigan Bridge and traversed the Willowbank Forest before traversing south to Wigan Bridge. The flight path and main image identifiers are shown in *Figure 31* below.

A meander loop immediately below the river crossing at Willowbank Forest shows a significant pile of slash caught up against willows on the river bank as well as silt deposition and bent over grasses marking the flood level (*Figure 32*). Upstream of the meander loop, the river crossing from Tauwharepare Road to Willowbank forest also showed significant signs of flooding as well as clearly evident cut pine logs lying on the crossing just above water level (Fig*ure 33*).

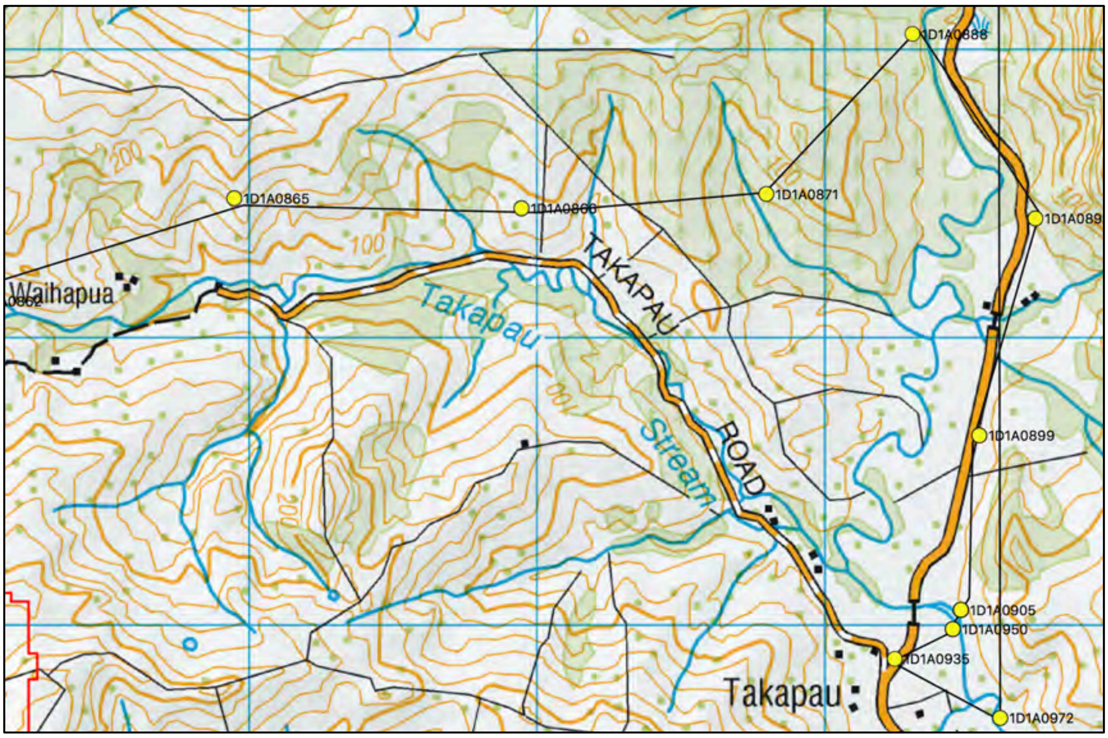

Figure 31. Flight path over the Tauwhareparae Road from Wigan Bridge to Willowbank

Figure 32. View of meander loop on the Mangaheia River immediately below Willowbank Forest showing woody debris caught up against willows as well as silt deposition. Note the two flood channels marked by discoloured pasture.

Figure 33. View of river crossing at Willowbank showing logs in the ford approaches and at river level.

The slash at Wigan Bridge is shown in *Figure 34* below. This shows the situation immediately following the immediate clean up to protect the bridge but before the remaining slash was put into 3 separate piles.

Figure 34. Wigan Bridge on the 21st of April showing the remaining woody debris as well as slash piles from an earlier event in 2015. Much of the debris was "released" into the river downstream.

Around 500m below Wigan Bridge, a large mass of slash within a meander loop was observed along with a fresh collapse of the river bank (Fi*gure 35*). The bent over grasses and colour contrast with the unaffected pasture gives an indication of flood height.

Based on a comparison of the volume of material at Wigan Bridge on the 18th of April (see *Figure 13)* and that shown in *Figure 35*, it is assessed that the debris in the river shown in *Figure Thirty Five* is most likely to be mainly composed of slash released from Wigan Bridge during slash clearance following Cyclone Cook. Based on a traverse undertaken on the 13th of May, this unconfined slash had largely mobilised further downstream during a small flood event around one week after the flight. No slash was subsequently observed between here and Tolaga Bay but significant volumes of new slash was reported on the beach.

Figure 35. Slash caught in a meander loop 500m below Wigan Bridge. .

3.4.5 Flight Segment Five; Mangaheia; Mangatoitoi and Mangateao

In some ways the overflight on the 21st April highlights the difficulties in assessing the environmental impacts of intense storms on plantation forests. This is highlighted in the flightpath over Everetts Road and the Mangatoitoi catchment (*Figure 36*). Only a few photographs were taken and these generally did not cover the main area of recently harvested forest.

Georeferenced image 1D1A0983 (*Figure 37*) shows a digger working to clear landslide damage from a forestry road in the small stream between the Mangatoitoi and Mangateao catchments. Image ID1A0981 (georeferenced) and image 092913 (located using topographic features in common with IDIA0983) show the impact of Cyclone Cook on forestry operational areas within the middle reaches of the Mangatoitoi stream. Image 092809 was also located using topographic features and shows levees of slash on the banks of the Mangateao Stream and on the top edge of Everetts Road as well slash piles at the catcher (*Figure 38*).

These images show that the flood event was extensive and occupied the entire valley floor and in *Figure 38* particularly demonstrate slash mobilisation. What could not be seen in *Figure 38*, however, was whether or not slash got past the slash catcher and reached the Mangaheia River itself. It was thus clear that this area required a more detailed investigation and this was duly undertaken over the following month.

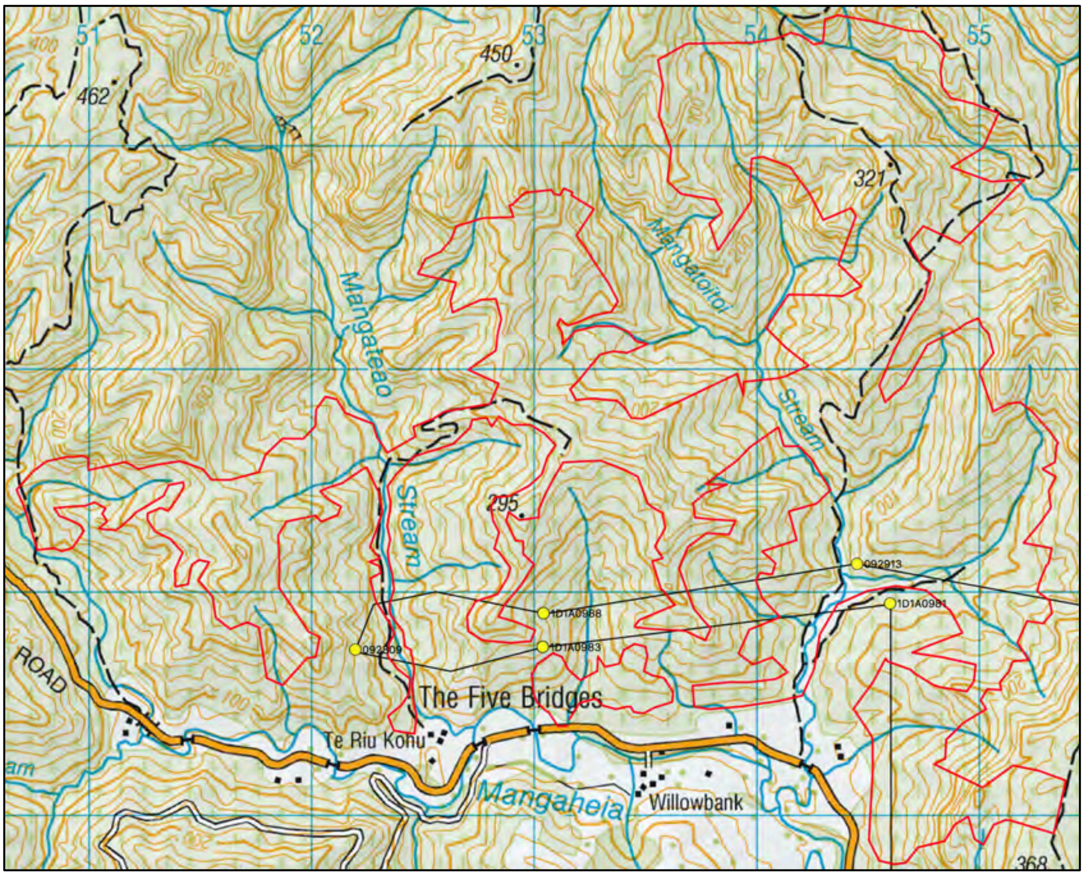

Figure 36. View of the forest area north of the Tuawhareparae Road (Everetts Road/Mangateao Stream and Mangatoitoi Stream) showing the flight path, photographic coverage and the extent of area harvested at 1 January 2017.

Figure 37. View of a digger working to repair a forestry road after a landslide.

Figure 38. View of the bottom end of the Mangateao Stream showing the slash catcher with debris jam (just above willows), a pile of slash on the true left of the stream above the level of the catcher and levees of slash on both sides of the river.

Georeferenced image 1D1A0981 and image 092913 (geo-located using topographic features) give an indication of the impact of Cyclone Cook in the Mangatoitoi Stream. The bottom end of the Mangatoitoi is shown in *Figure 39* while *Figure 40* shows a view up Mangatoitoi from approximately the same position.

Figure 39 shows the characteristic texture associated with grasses lying in the direction of flow suggesting that the flood heights in the catchment were above the river flats while logs can be seen at the bottom left of the image suggesting mobilisation of slash. *Figure 40* shows a birds-nest of logs forming a dam across the river and slash stored on the true left bank of the river. As was the case with the Mangateao River, there were some indications of mobilisation of woody debris and it was clear that this area required further investigation.

3.4.6 Flight Segment Six; Tapuae stream area

Tapuae Stream is located partway between the Mangaheia and Mangatokerau Catchments and has been largely harvested between 2013 and January 2017 (*Figure 41*). A large suite of images was taken in this general location (Georeferenced images 1D1A1005 to 1D1A1078). Two images have been selected from this suite for discussion here and the remainder are documented in **Appendix One**. This stream is characterised by areas of slash forming small dams, as well as slash either stored or scattered across the flood plain (Figu*re 42*).

The upstream end of the harvest area is in similar condition (*Figure 43*) but there were no reports of debris from this area discharging out into the main water ways. This is probably primarily due to the small catchment size and also the large number of willows in good condition below the harvest area which caught a lot of the debris. Unfortunately, the flight path did not follow the stream down onto farmland and so this could not be assessed at the time. Some pine slash was subsequently located below the Paroa Road bridge.

Figure 39. View of the lower Mangatoitoi River showing the pale texture resulting from flattened grass on the flood plain and scattered logs on the lefthand side of the road (bottom left).

Figure 40. View looking up the Mangatoitoi shows slash in the middle reaches and stored against the flood plain on the true left bank (bottom right).

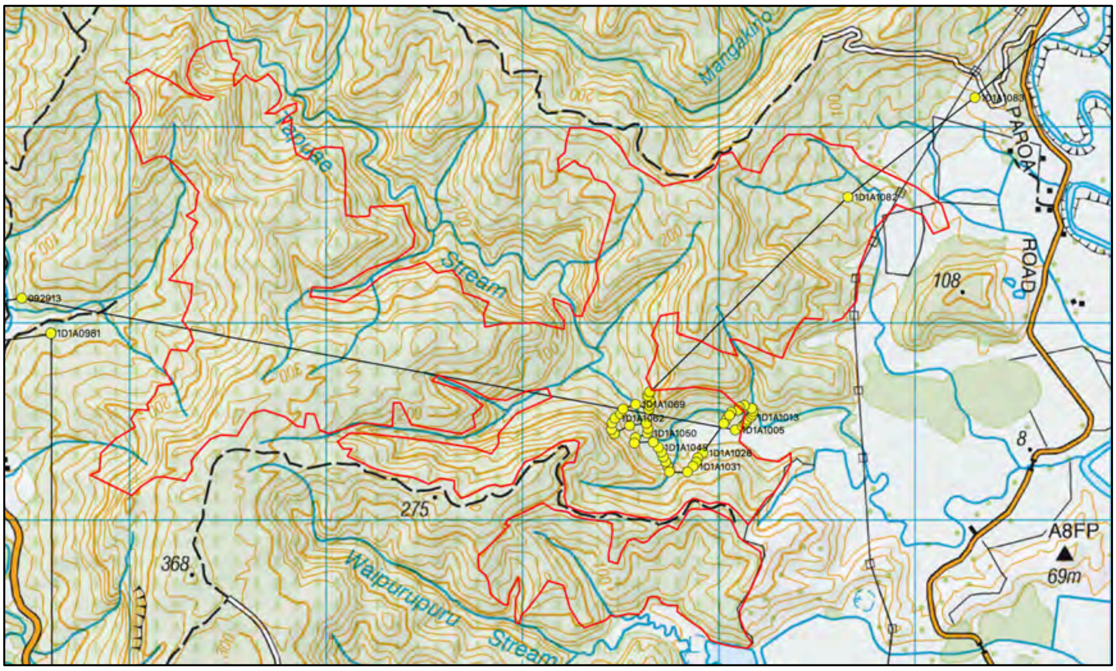

Figure 41. Tapuae Stream located between the Mangaheia and Mangatokerau catchments showing the flight path and image locations and the areas harvested by January 2017.

Figure 42. Lower end of Tapuae Stream showing logs forming birds-nests across the water course and either stored or scattered along the flood plain.

Figure 43. Upper reaches of harvest area in Tapuae Stream showing a birds-nest of slash damming the watercourse and generally high levels of slash either scattered or stored in vulnerable locations on the flood plain.

3.4.7 Flight Segment Seven; Mangatokerau

The Mangatokerau Catchment (*Figure 44*) was a principal focus of the overflight since both the newspaper reports and the immediate on-site rapid assessment indicated significant mobilisation of slash in this area and it was the site of one of two significant debris flows generated during Cyclone Cook. As a result the over flight of this area was relatively comprehensive and particularly focussed on the east facing slopes where the debris flow originated.

Figure 44. View of the Mangatokerau Catchment showing the area harvested as at 10th of January 2017, the flightpath and the key images used in this analysis.

The impact of Cyclone Cook on the Managtokerau is highlighted by the damage evident downstream of the forestry areas. Image 1D1A1097 (*Figure 45*) shows the flood extent upstream of the house that was at risk during the event with significant silt and woody debris deposition showing the lateral extent of the flood. The impact is even more marked in the area downstream where large slash piles can be seen lodged against standing vegetation on the flood plain (*Figure 46* Image 1D1A1114). Further downstream both the volume of woody debris and the extent of the flood spread is evident with the discolouration of the grass showing how close to the house the flood was (*Figure 47 Image 1D1A1174*).

Figure 45. View looking upstream in the Mangatokerau (image 1D1A1097) showing silt and woody debris deposition.

Upstream of the areas shown in *Figures 45* to *47*, the debris flow documented in the rapid assessment was clearly evident in *Figure 48* and shows the headscarp at the top of a unnamed creek referred to here informally as "Waterfall Creek". This demonstrated that the debris flow originated at a landing above this steep slope and travelled down the creekbed to its base (*Figure 49*) triggering sidewall collapses through undercutting in its passage. By the time of the overflight, the forestry company operating in the area had already cleaned up the base of the debris flow. This meant that it was not possible to assess the scale of the debris flow apron or its character (ie the vicosity of the debris flow materials). The Waterfall Creek debris flow is discussed in more detail in the next section.

Further north from Waterfall Creek, the flight took in views of Mangaonui Stream where a series of birds-nests of slash formed dams in the stream (*Figure 50*). West of Mangaonui Stream similar masses of slash within the water course could be observed in Tohitu Stream.

Figure 46 . Image 1D1A1114 showing the view downstream of Figure 45. The full width of the valley extent of the flood is evident from the discolouration and grass texture of the paddocks. The large piles of slash and silt deposition are also evident in the foreground.

Figure 47. View of the farmhouse in the Mangatokerau Valley showing how close the flood and woody debris came to impacting on the farmhouse (Image 1D1A1174). The light coloured band upstream of the hosue is a bund the landowners have constructed to protect the house from flood events.

Figure 48. View of the Mangatokerau debris flow in "Waterfall Creek" with a headscarp adjacent to a landing and with a secondary debris flow path at the bottom of the image. There is indigenous vegetation at the base of the image below the debris flow and on the right of the photograph.The debris flow was, however, entirely within the cut over pine slopes and the indigenous vegetation was unaffected.

Figure 49. View of the debris flow fan base of "Waterfall Creek", Mangatokerau River showing the significant silt and slash deposition.

Figure 50. View of Mangaonui Stream showing woody debris caught up in the watercourse.

3.4.8 Flight Segment Eight; Mata River and Whakoau Stream

The Mata River area had not been visited during the rapid assessment process nor were any reports of forestry slash events received from companies operating in the area. It was, however, a logical place to assess during the overflight and informal reports were subsequently received about some slash caught up against the bridge at Bremner. This over flight assessment is divided into two parts, the Mata south of Bremner (*Figure 51*) and the Whakoau upstream of Bremner Bridge (*Figure 52*).

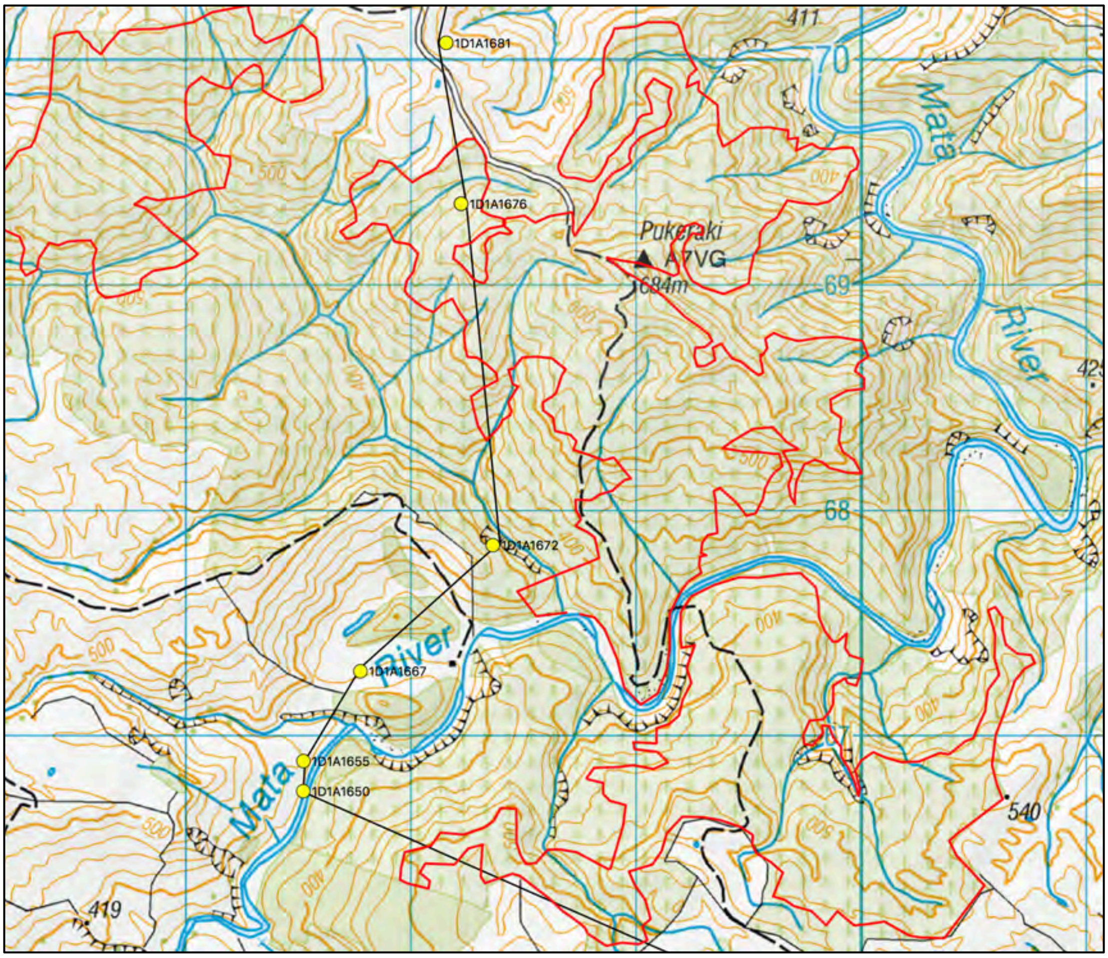

Figure 51. View of the headwaters of the Mata River showing the areas harvested up until the 25th December 2015, the flight path and image locations.

The number of images taken of the Mata River during the over flight was relatively low. Images 1D1A1650 and 1D1A1655 shows that some windthrow pine logs reached the river due to pines being planted at the top of an unstable face (**Appendix One**). There was, however, no indication of mobilisation of either slash stored on the flood plain or pine logs mobilised by debris floods or flooding.

The situation at the Whakoau Stream was rather different, however, with a large series of images indicating mobilisation of pine slash stored on the rivers' flood plain. This area had been identified as being at risk during a flood event during a site visit in December 2016 and indicates that landing and operational parameters at this site did not adequately address the risks associated with the landing site. This area is discussed in more detail in the next section of this report.

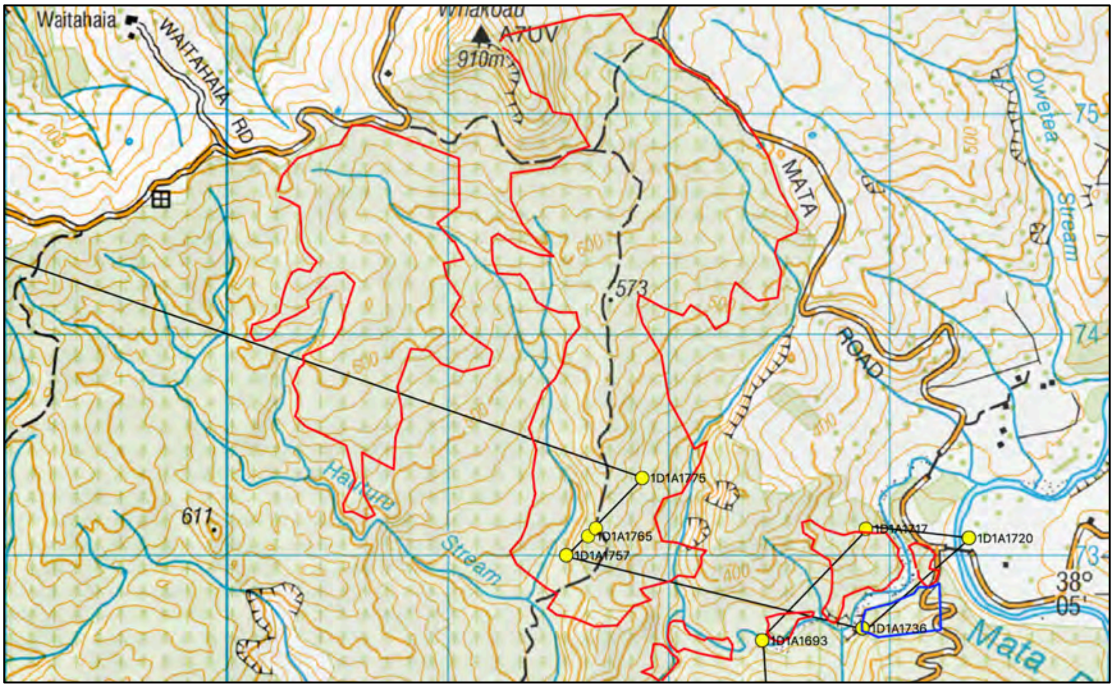

Figure 52. View of Whakoau Stream showing the areas harvested up until 25 December 2015, the area harvested between December 2016 and January 2017 (Blue), the flight path and image locations.

3.4.9 Flight Segment Nine; Ruatahunga Stream, Waiapu Catchment

The last feature assessed during the overflight was a major landslide in Ruatahunga Stream, a headwater tributary of the Waiapu (*Figure 53*).

Figure 53. View of pre-existing landslide in Ruatahunga Stream showing some signs of remobilisation.

This landslide had indications of some recent slope movement, probably related to Cyclone Cook. The feature was, however, also pre-existing and was evident on the published 1:50,000 topography map and Google Map Pro imagery going back to January 2003. Some mobilisation of trees on the landslide may have occurred but the landslide is considered a largely pre-existing feature reactivated during the storm. Some slash can, however, be seen on the river banks below the landslide.

3.4.10 Summary of Flight Findings

The flight highlighted the value in using a helicopter to more effectively assess the impacts of the impacts of the cyclone but also allowed for some tactical lessons to be applied to the next event;

a. The value of georeferenced photographs has been demonstrated but in future such photographs should be acquired from both sides of the helicopter as it was found that considerable effort was required to locate non-georeferenced images on the ground post-flight.

b. That a smaller more cost-effective helicopter is used with less people on board allowing for a greater area to be covered for less cost and reducing the impact on staffing in the event of an accident.

c. That more pre-flight planning is undertaken to ensure that all areas of relevance are covered in the flight.

d. In the future it may be more cost-effective to use a suitably configured fixed wing aircraft or a smaller helicopter.

e. Not-with-standing the above, the flight did identify most areas of relevance for subsequent more detailed follow-up.

In Waimanu Forest only minor landslideping was observed but there was some mobilisation of woody debris indicating that some slash had been stored within areas at risk of flooding. Some slopes were untidy with slash caught up in gullies in the upper parts of slopes. These could mobilise during an event bigger than Cyclone Cook. Further north in the Waimata Valley on Duncan Road near Wakaroa, several fresh new small landslides were observed associated with road cuts along with a number of pre-existing larger landslides. No mobilisation of slash was observed but again slopes were observed with slash in the upper parts of gullies. No significant landslides were observed in the Hokoroa Road area but there was slash stowage close to rivers that would be at risk of mobilisation during an event bigger than Cyclone Cook.

The upper Tauwhareparae Road was a key area for investigation but apart from the Doonholm landslide only small amounts of landslideping were observed. At Willowbank logs were observed at a crossing while the significant extent of slash in the Mangaheia was evident both at Wigan bridge and in meander loops in the river downstream. Upstream at the Mangateao and Mangatoitoi streams, and in the area between there were clear signs of slash mobilisation, landslides, and debris on the flood plains. In Tapuae Stream there was no indication of debris flows or slope failures but slash management within the catchment was poor with considerable woody debris stored and scattered throughout the flood plain and caught up in the stream bed.

The Mangatokaerau River showed significant impacts and was one of only two catchments with major debris flows observed. It was also observed that while the debris flow was a major source of woody debris on the flood plain upstream of the Waterfall Creek debris flow, it was not the source of woody debris widely present on the flood plain. Such slash on the flood plain would be prone to mobilisation during an event larger than Cyclone Cook.

In Mata River, some transport of largely windthrow pine to the flood plain was observed but there were no indications of significant debris flows or downstream migration of slash. At Whakoau Stream, the slash catcher failed but the over-flight showed no signs of significant debris flows but did indicate that there was a considerable amount of woody debris on the flood plain in the harvest areas upstream of the slash catcher. The flight path did not cover the lower reaches of the Waiapu Catchment and hence migration pathways for the slash that overtopped the slash catcher cannot be established. At Ruatahunga Stream a major slope failure was observed but subsequent investigations showed that this was largely pre-existing.

Overall, the flight indicated that the Mangatoitoi, and Mangateao streams in the Mangaheia River, and further north the Managtokerau were areas for further investigation along with Whakoau Stream. More generally, it was observed that;

a. Well establish indigenous vegetation or willows in riparian margins were were significant in being effective in reducing the downstream migration of slash (see *Figures 26, 32*).

b. Apart from the pre-existing Doonholm Landslide, the slope failures observed were not randomly distributed but were strongly associated with landings and roads on or adjacent to steep slopes.

c. There was also an association between the larger failures and north east or northerly facing slopes.

d. A large amount of woody debris was observed either stored or scattered on flood prone sites such as flood plains or in gullies which would be vulnerable to mobilisation during an event larger than Cyclone Cook.

e. A large amount of the woody debris appeared to be logs with cuts rather than windthrow.

f. A majority of harvested areas could be best described as untidy with widely distributed woody debris on slopes, gullies and unstable piles.

g. Despite the relatively small scale of Ex Tropical Cyclone Cook slash and sediment mobilisation into the rivers was significant.

4.0 Detailed Site Investigations

4.1 The Tier 3 Assessment

The 3 tier protocols to capture data was developed for the Gisborne District Council by Landcare Research and described by Phillips, *et al* (2016) as paraphrased below.

The detail required at Tier 3 level includes aspects of both Tier 1 and 2, but with further additional quantitative data/information including subsequent analysis (See Table Three). This approach requires considerable effort and time and hence is of moderate to high cost. It may require specialist expertise not available in house. It is more likely to use a combination of electronic field data capture and then on-line database storage, retrieval and analysis including spatial modelling. Results from such assessments are not usually available for some months following the event. This information has wider utility, informs national-level understanding of natural hazards and their management, and enables the development or refinement of risk management approaches (risk matrix).

The Tier 3 approach recommended by Phillips et. al (2016) has not been completely followed in this investigation. This is primarily since slash mobilisation occurred but debris flows were only established as a cause in one case, hence, a broader perspective was required. None-the-less, as much as possible, the data that Phillips *et al* (2016) recommended be collected was gathered but adapted for the circumstances of this storm.

This detailed assessment therefore follows the catchment (and sub-catchment) and forest name approach recommended but it was decided that the identification of specific forest owners did not need to be documented. The methodology followed for this investigation comprised the following elements;

a. Catchment and sub-catchment level tracking of woody debris from impact point to source.

b. Use of georeferenced photography to document individual debris piles or individual logs.

c. Use of a drone to undertake a rapid assessment of areas too risky or time consuming to traverse on foot.

d. Conversations with landowners in impacted areas or adjacent to water courses where woody debris migration was observed.

e. Use of a digger to deconstruct slash piles so that the types of woody material present could be quantified.

f. Use of council staff and local school students to quantify the types of woody material present on Tolaga Beach.

g. Review of incident reports supplied by a forestry company.

h. Digitising the areas of forest harvested since the date of council aerial Photography (2012-13) using time-series satellite imagery available on Google Earth Pro.

i. Analysis of the weather conditions by using rain gauge and flood level data.

Catchment Forest Names	
Geology	Age Lithology Regolith type and weathering
Topography	Slope steepness Land Use Capability group or angle Aspect Local relief factors
Severity of erosion Type of erosion Landslide numbers	
Landslide details	Slope position Failure mechanism Material Landslide density (#/ha) Landslide size Landslide Volume Landslide connection to watercourse
Vegetation	Vegetation type Vegetation coverage percent
Weather conditions	Storm Name Dates Rainfall Duration Intensity Annual recurrance interval Antecedent ground and soil wetness condition Storm type Wind Direction Flood details
On site details	Time since harvest ownership within forest failure type Forest infrastructure damage landing failure Wind damage
Off site impacts	Presence of debris flows sediment migration beyond forest woody debris in rivers/beaches Damage to public infrastructure River bank slumping
Forest Company Response within forest Forest Company Response to neighbours	

Table 3. Example of the type of information to be collected during a Tier 3 Investigation after Phillips et. al. (2016) (some of this information would be recorded irrespective of whether or not a Tier 3 investigation is warranted). In the case of Cyclone Cook it was found that some of the underlying assumptions in Phillips et al (2016) did not apply and hence this table is only a guide.

4.2 Uawa Catchment

The Uawa Catchment comprises several sub-catchments, the Hikuwai, Mangaheia and Mangatokerau which merge to form the Uawa and discharge into the sea at Tolaga Bay. The initial rapid assessment and overflight lead to attention being focussed on Mangaheia and Mangatokerau streams.

4.2.1 Mangaheia River

4.2.1.1 Doonholm landslide

The Landcare Research advice (Phillips *et al* 2016) was predicted on the assumption that significant landslides and debris flows or landslides were the primary mechanism for mobilising forestry slash on slopes and transporting this debris to the water courses. The Doonholm landslide west of the 5 Bridges on Tauwhareparae Road in the Managheia Catchment failed during Cyclone Cook and was one of two significant landslides observed during the event.

Doonholm Landslide is a complex pre-existing debris flow associated within a mature exotic forest. The Tauwhareparae Road in this area is oriented roughly East-West and the landslide is situated on the south side of the road and thus faces north north east. The headscarp was located in undifferentiated Pliocene mudstones, and alternating sandstones of the Mangaheia Group while the body of the debris flow is underlain by Miocene aged interbeddeed sandstones and mudstones of the Tunanui Formation (*Figure 54*). The entire landslide is classed as 7e15 in the landuse capability classification and has an approximate slope angle of 30°.

Figure 54. Coarse scale geology of the Doonholm Landslide (outlined in black) based on the 1:250,000 Raukumara Geological map (Mazengarb and Speden, 2000). Pliocene Mudstones on left and undifferentiated Miocene Mudstone and alternating sands on right.

As a consequence of the initial assessment, the expectation was that the landslide (Figure *55*) was a major contributor to the Wigan Bridge slash event (see Figure *54*). A detailed assessment of the Doonholm landslide was undertaken on the 13^{th} of May. It was found that the landslide debris terminated at the road which had acted as an effective berm which would have resulted in an immediate reduction in flow velocity causing the landslide to lock up. The inspection indicated that while the landslide above the road was deeply scoured there was an absence of scour below the road. Indeed the only material on the downhill side of the landslide was material stored there during the landslide clearance process (Figure *56*).

Figure 55. View of Doonholm landslide showing both the head scarp and the depositional zone post clean up by Tairwahiti Roads.

A series of photographs of the debris flow were subsequently supplied by Tairawhiti Roads. The images are low quality and are not geo-referenced but do give an indication of the mechanisms at play during the event. The headscarp is shown in *Figure 57* and shows that the failure resulted from a slump in the headwall and the migration of regolith downslope. Significantly, this material retained some structural coherence and the boundary between mobilised slump material and the flow material was distinct which is consistent with a debris flow mechanism. Other photographs indicate that the debris on the downhill side of the road was placed during post storm remediation. No sign of mud or woody debris was seen below the road.

Figure 56. View of the Doonholm landslide debris below the Tauwhareparae Road. Note the lack of mud or debris below the road other than that moved during road clearing operations.

Figure 57. View of the headscarp of Doonholm landslide. This shows that failure was initiated by slumping at the headscarp with this material some initial coherence but triggering chaotic flow in the gully below.

Because the area below the Doonholm Landslide was difficult to access, a Phantom 4 Pro drone was used to fly the river from immediately below the landslide to Everetts Road. The drone followed a specified grid plotted with *Drone Deploy* software designed to provide good overlap between images. This allowed for a 3.5 km stretch of the river to be covered in about an hour (*Figure 58).* Three hundred sharp georeferenced images were obtained and processed overnight in *Pix4D* to generate a photomosaic and point cloud. The point cloud data was then loaded into *Cloud Compare* to allow for 3D manipulation of the image.

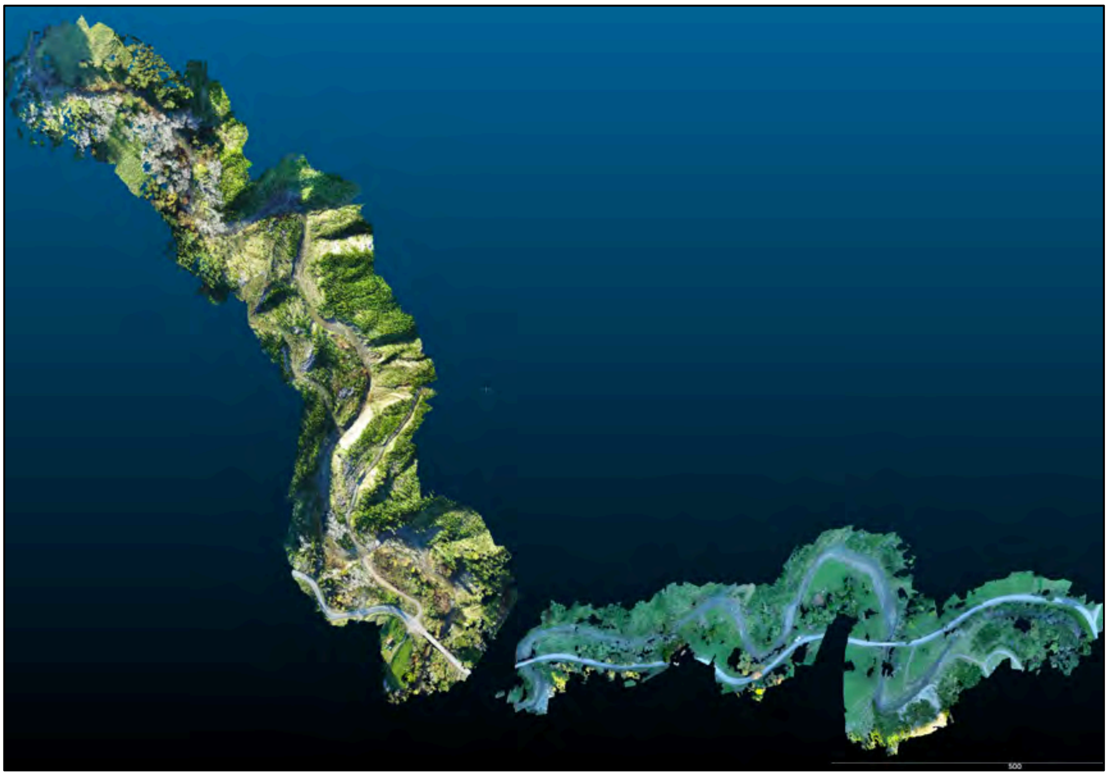

Figure 58. Dense point cloud of the Tauwhareparae Road drone flight (Cloud Compare screenshot) showing the two flight segments and degree of coverage up the river from the junction with Everets Road (far right) to just below the Doonholm Landslide.

A scan of the image showed that there was no signficant debris in the river either at the point closest to Doonholm landslide or from there to Everetts Road (Managteao Stream). The image file was examined in detail, particularly where a small landslide on the true left bank had originated from a failed forestry road edge to see if that had sourced debris to the river as well as other small-scale bank failures (*Figure 59*). This also allowed for areas replanted in pines on the flood plain to be looked at closely to see if any of the slash stored in this post-harvest had been mobilised. (*Figure 60*). It was concluded that the Doonholm Landslide did not contribute to the slash event observed downstream nor were there signs of significant mobilisation of slash in the stretch of the Mangaheia upstream of Everetts Road (Mangateao stream).

Figure 59. Detail of an individual drone flight image (DJI_0202) showing riverside slumping and unmobilised slash within an area of replanted pines.

Figure 60. Point cloud imagery of a bend in the Mangaheia River showing slash piles stored on the flood plain replanted with pine.

4.2.1.2 Mangateao Stream

Based on *Figure 38* above, which showed a line of woody debris at the flood height on the true left of the stream and debris piles at the slash catcher, Managateao Stream was a focus of attention. The bottom end of the catchment was thus visited several times (17th April, 13th May, 16th May, 9th and 11th June, and September 3rd). The visits focussed on the area where slash was observed during the flight and the area from Everetts Road to Willowbank Farm. The landowner at the bottom of Everetts Road was also interviewed.

In effect, these site inspections just highlighted what had been apparent from the flight. Namely, that a significant amount of slash had been mobilised in the catchment. The farmer confirmed that the slash catcher had been cleared and repaired. No incident report was received from the forestry company operating in the forest but they subsequently advised that the catcher did not need repair. Judging by the amount of material cleared from the catcher it was overtopped distributing slash downstream.

The Everetts Road area and the Mangaheia River downstream of Everetts (Mangateao Stream) are shown in *Figure 61* below. This shows the end of the drone flight (red line) at left, as well as key geo-referenced photo points in the Managheia below Everetts (green circles). The red circles are images taken at the cleared and repaired slash catcher within Mangateao Stream (*Figure 62*) and looking upstream from the slashcatcher showing the logs at flood height (*Figure 63*).

Figure 61, View of Everetts Road (Mangataeo Stream) area in the Mangaheia showing the location of georeferenced photographs and the end of the drone flight path.

Figure 62. View of the cleared slash catcher on Mangateao Stream. Note the presence of logs on the riverbank, middle background below the catcher and the flood height above catcher height on the true left. This catcher is under-engineered for the catchment.

Figure 63. View up Mangateao Stream showing a levee of slash at flood height on the true left bank.

The area of the Mangaheia river traversed and the GPS observations are shown in green in *Figure 61* above. In the meander loop between the two bridges, the GPS recorded flood heights and the associated photo recorded logs and other features are shown. A feature of these photos are that they are dominated by weathered old cut pine logs with subordinate dross and some willow. As the old logs frequently still showed un-abraded cut ends they are interpreted as logs that were stored in a vulnerable location and mobilised during the event.

Above the second bridge, the character of the debris changed and was dominated by willow, some dross and occasional pine logs. Noteably, the log jam at the old bridge site is present in Google Earth Pro imagery in 2016 and 2017 but absent in imagery dated 17th January 2015. This material was therefore most likely pre-existing and mobilised during 2015, although that year's storm event was primarily centred on the Wharerata Ranges. The river bank was traversed above the old bridge to above Everetts Road and no further woody debris of significance was located.

At the point where the Mangateao stream joins the Mangaheia River, a farmers debris catcher was located but was damaged and was below maximum flood height. Woody debris was again observed on the streams banks upstream of the catcher. It seems clear that the slash catcher in the Mangateao was at least partially effective but was overtopped due to the flood height being above the top of the catcher and hence debris could mobilise downstream. This aligns with the local farmer's observations of a *"wall of wood"*. This sub-catchment thus may have been one of the sources of debris downstream at Wigan Bridge but the contribution is not quantified and no debris was observed in the river at Willowbank farm 550 metres further down stream.

No debris flows were observed during the overflight but that does not preclude there being a small unobserved event within the catchment. No fresh logs or windthrow pine were also observed nor was a significant sediment load observed in the river. Overall, the predominance of old logs and lack of fresh logs suggests mobilisation of pre-existing stored slash rather than debris flows was the driver for the slash generated in the Mangateao.

4.2.1.3 Mangatoitoi Stream

Mangatoitoi stream, a tributary of the Mangaheia was first visted on the 13th of May and then again on the 16th of May, the 17th of June, and the 3rd of September (*Figure 64*). As was the case with the Mangateao stream, no incident reports were received from the forestry company operating within the catchment. The flight path did not fully cover the catchment but the active operational area was imaged (*Figure 65*) and did not indicate the presence of any significant slope failures. What is clear from *Figure 65*, however, is the presence of a pronounced levee of slash on the true right bank below the bird's nest of slash caught up in the slash catcher. This indicates that while the slash catcher caught some woody debris far more was able to overtop the catcher and migrate downstream.

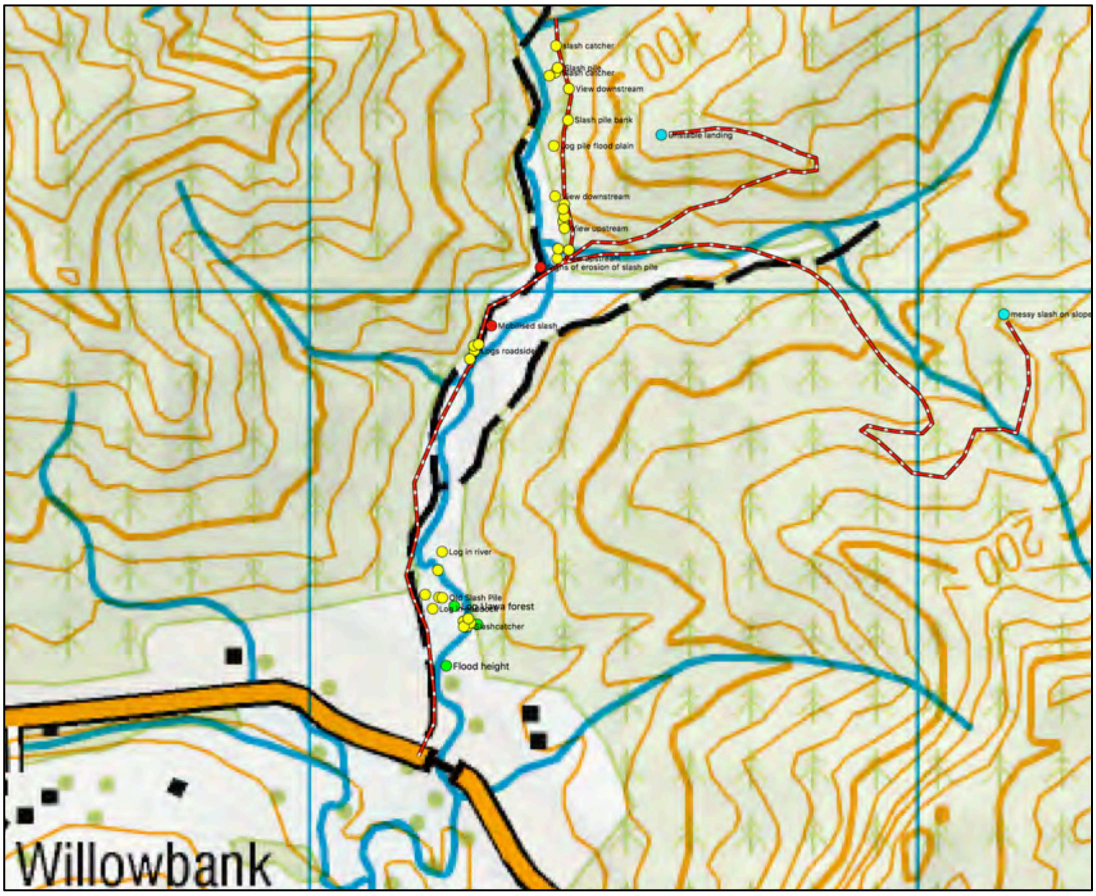

Figure 64. Plan of the Mangatoitoi sub-catchment showing the route taken as well as photograph and observation sites.

By the time the field inspections were undertaken the slash catcher had been cleared and repaired but there was considerable slash identified over the length of the stream from the top catcher to a second slash catcher just before Tauwhareparae Road (*Figure 66*). Additionally there were piles of slash stored on the west side of the road which showed signs of significant edge erosion indicating that essentially the entire width of the valley was flooded. The actively harvested area was scanned from an unstable landing above the valley but no sign of significant slope failures were observed.

The lower slash catcher showed no signs of being cleared or repaired and while it had some debris caught against it (*Figure 67*), there was also woody debris downstream of the catcher indicating that the catcher had been overtopped. A wider examination of the true right bank showed that the meander loop within which the slash catcher was constructed was bypassed by a low-lying area of paddock that formed a channel between the stream and the access road to Mangatoitoi stream transporting some material (*Figure 68*).

Figure 65. View looking up the Mangatoitoi Stream showing the levee of slash in the foreground and a birds-nest of slash caught up in the slash catcher further upstream. At bottom right the stored slash remained largely intact with some erosion of the base. In the background is the operational area with no signs of significant slope failures.

Figure 66. View of mobilised slash on the lefthand side of the forestry access road in the Mangatoitoi Valley. This material comprises fresh cut pine logs along with fine dross along with silt.

Figure 67. Bottom slash catcher in Mangatoitoi Stream showing woody debris caught against the catcher on the true right bank with a mix of willow, small pine and dross with consideable frsh silt deposited.

Figure 68. Bypass flood channel in Mangatoitoi Stream between the stream (out of view left) and the forestry access road. Note the long resident pine log in the foreground and smaller debris caught against the small slash pile from an earlier event. It is not obvious in this view but some cut logs are evident caught in a gap in the trees in the middle background and a pre-existing slash pile against the trees to the left of the gap.

Based on the field investigations, is it considered that a considerable volume of slash had been mobilised in the Mangatoitoi Valley. Both the upper slash catcher and that close to Tauwhareparae Road showed evidence of overtopping and bypass, and the lower catcher in particular was located in a meander loop that was by-passed completely by a channel. As the full width of the valley was flooded, slash was able to reach the Mangaheia across flooded lowlying paddocks. Both the overflight and field inspections showed that slash had been stored in vulnerable locations within the catchment where it was able to be mobilised during Cyclone Cook (additional images of the Mangatoitoi are shown in **Appendix One**).

The data for the Mangatoitoi shows that it is a likely source of at least some of the debris that was caught up at Wigan Bridge. Accordingly, the accessible stretch of the Manageheia River below Mangatoitoi stream to the Willowbank forest river crossing was traversed on the 17th of June to establish where or not there was evidence of fresh slash in the river. This area is shown in *Figure 69* below.

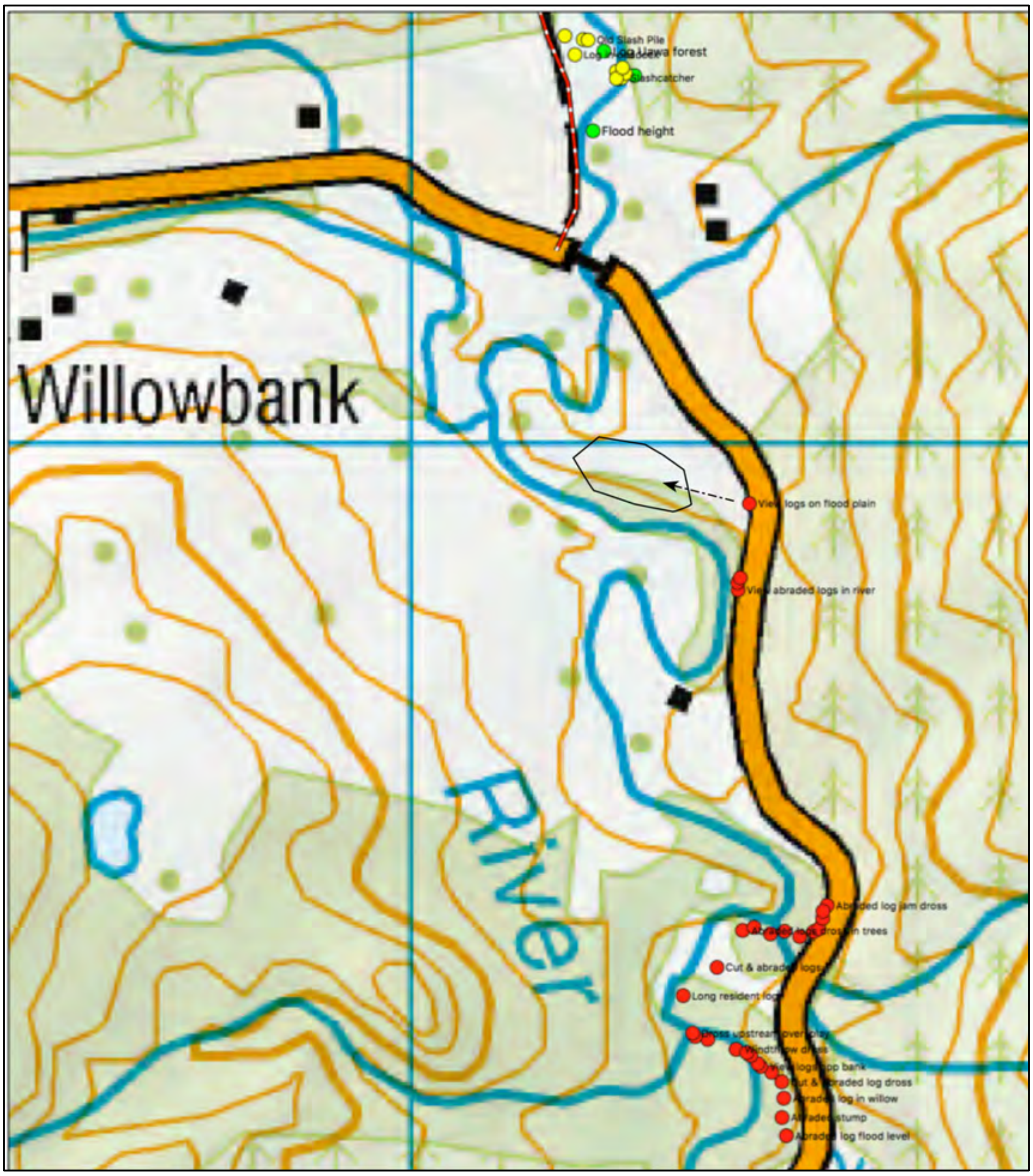

Figure 69. Map of the section of the Managheia River below the confluence with the Mangatoitoi showing the location of photographs taken of logs.

There was a significant volume of slash in this section of the river although less concentrated than in the Mangatoitoi or present closer to Wigan Bridge (see below). The proportions of different woody debris types has been estimated by counting the different types of logs in each photograph. Since the dross comprises aggregated fine sized material this was estimated by assigning a count of "1" to a small amount, a "2" to a moderate amount and a "4" to a large dross pile. This analysis indicates that the woody debris was dominated by abraded or old pine logs and dross with moderate amounts of windthrow pine and willow, and small amounts of cut or fresh broken end pine (*Figure 70*). In percentage terms, 38% was abraded pine, 6% was cut pine logs, 3% fresh broken pine, 10% windthrow, 30% dross and 13% willow (*Figure 71*). When aggregated, pine comprised 57% of the total material. A typical situation with largely abraded logs, dross and small amounts of probably windthrow and willow caught up against a tree is shown in *Figure 72* below.

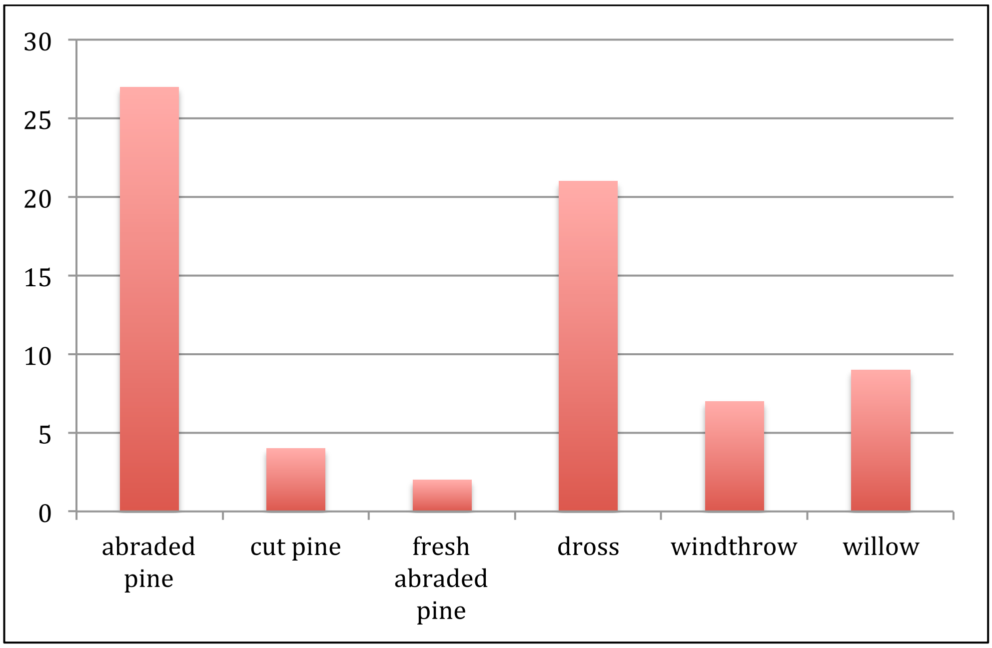

Figure 70. Number of the different types of woody debris in the stretch of river between the Managtoitoi to just above the Willowbank Forest river crossing.

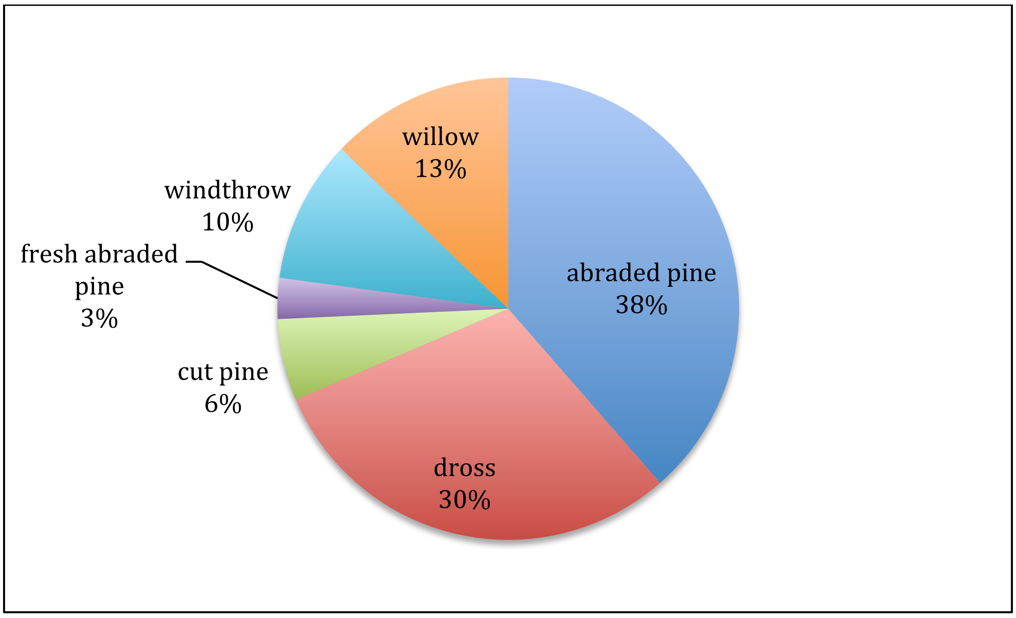

Figure 71. Woody debris in the Managheia between the Mangatoitoi and Willowbank Forest expressed as a percentage.

Figure 72. Abraded logs and dross with minor willow and windthrow about halfway between the Mangatoitoi and Willowbank Forest.

4.2.1.4 Willowbank Forest River Crossing

The Willowbank Forest river crossing was visited on June 17th to assess whether or not this area had contributed to the slash at Wigan Bridge. This possibility was indicated by the imagery collected during the overflight (see *Figure 33*) which suggested that logs may have been mobilised. This crossing was used to access the recently harvested forest and was consented for temporary culverts.

This was confirmed during the on-ground assessment which established that the river crossing had been constructed using cut pine logs to form a corduroy base to the access road rather than a culvert. The location of the photographs taken during this assessment is shown in *Figure 73* below along with the position of the access road digitised from recent imagery in Google Earth Pro.

The construction of the corduroy base to the road can be seen in *Figure 74* and as this image makes clear, a number of the logs making up the corduroy have been washed away during the flooding during Cyclone Cook. The true right bank of the river can be seen in *Figure 75* and also shows silt deposition during the flood with two partially buried cut logs and two other cut logs below flood level. The remaining logs that made up the corduroy pre-flood appear to have been washed away. Poorly stored cut logs positioned at flood height are shown in *Figure 76. F*urther work is required to establish whether logs from this stow were mobilised during Cyclone Cook.

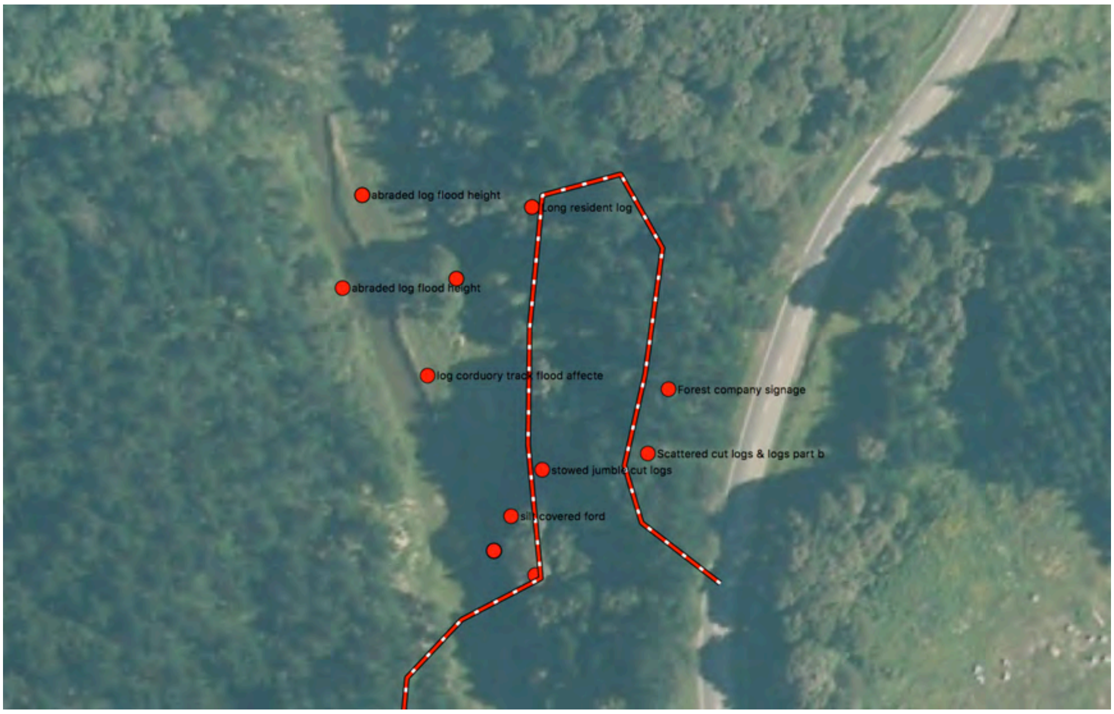

Figure 73. Map of the Willowbank Forest river crossing area off the Tauwhareparae Road showing the location of the acces road and photographs taken during the inspection.

Figure 74. View of the corduroy base to the river crossing on the true left bank of the Mangaheia River at Willowbank Forest. Note the silt deposition from the flood and the loss of logs.

Figure 75. View of the true right bank of the Mangaheia River at Willowbank Forest showing two logs from the corduroy remaining and two further logs at flood height.

Figure 76. Poorly stored cut logs located at flood height at Willowbank Forest.

Willowbank Forest is close to Wigan Bridge and was partially harvested in 2016 (*Figure 77*). An area of slash and the two flood channels downstream of Willowbank was shown in *Figure Thirty Two* above. While the catchment area is not large, a close examination of the area in *Figure 32* indicates that slash was also mobilised in the small stream that the Willowbank access road follows. The banks of the flood channels lack sign of woody debris which may suggest that the channels were only occupied by flood waters rather than significant debris at peak flow (*Figure78*) [Note that the photo in *Figure 78* has been processed in Adobe Photoshop to assist with identifying the areas of interest but the processing was limited to reducing the shadows in the top right of the photo. The overlays were drawn on top of the image using Autodesk Graphic].

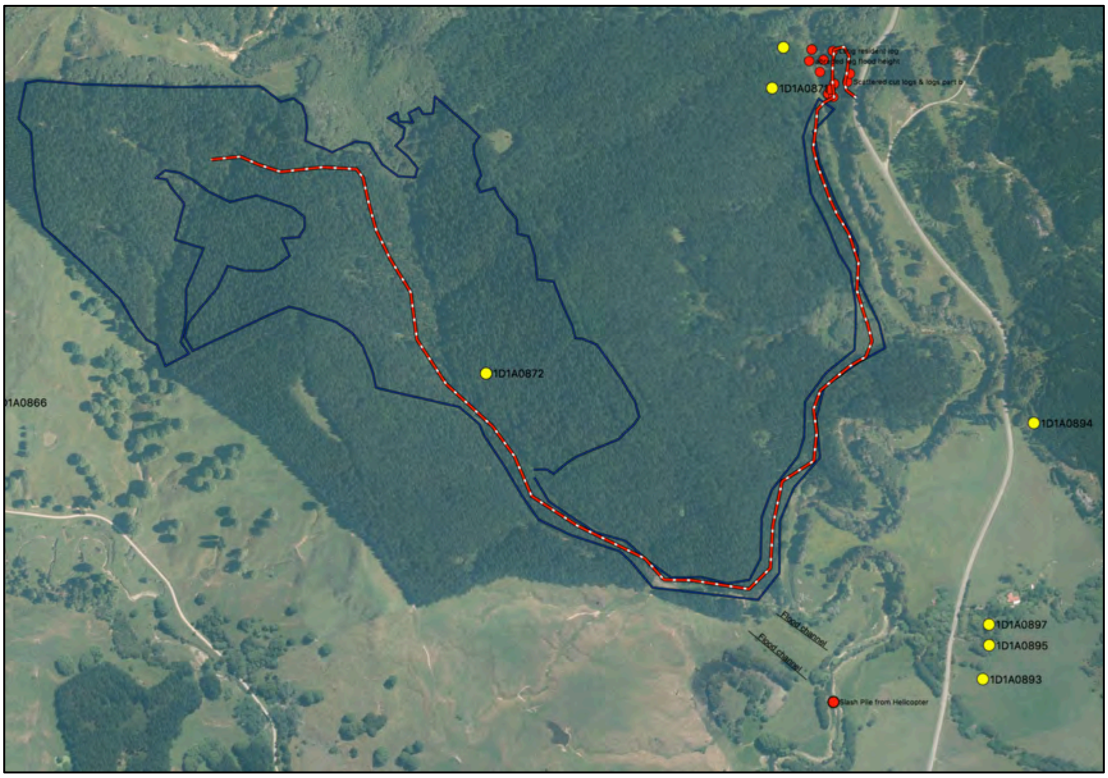

Figure 77. GIS output of the Willowbank Forest showing the area harvested during 2016 (blue line), the access road (red) the location of the river crossing at top right (red circles), the images taken during the overflight (yellow circles) and the location two two flood channels and a large slash pile at bottom right (red circle).

4.2.1.5 Willowbank to Wigan Bridge

The area below Willowbank to Wigan Bridge was traversed by a Land and Soil team on the 12th of June who identified a considerable amount of slash and it was thus traversed again on the 17th of June to allow for a detailed assessment of the quantities and types of woody debris in this stretch of the Mangaheia River (*Figure 79*). This area had the largest volume of material observed in all of the traverses of different sections of the Mangaheia River and has allowed for a quantification of the material by the type of material (*Figure 80*) and then recalculated as a percentage (*Figure 81*).

A margin of error of 10% is allowed in this data, since counting the different types of debris falling within sometimes quite messy slash piles, is difficult (*Figure 82*). Overall, however, the results are consistent with the results achieved at Wigan Bridge where a more accurate quantification of woody debris could be achieved. As was found elsewhere, the dominant type of material were pine logs that show signs of being within the river system for some time. These can have rounded or cone shaped ends but sometimes the ends are at right angles to the log indicating that they were cut at some stage.

Two abraded logs were found with waratah marks (*Figure 83*). Fresh cut pine logs were a small but significant portion of the debris (*Figure 84*) and windthrow pine negligible. Willow and unidentifiable small "dross" were significant but were proportionally less than pine materials. Much of the willow appeared to have failed but remained *in situ*. Several willows were cut.

Figure 78. Detail of the same base image as Figure Thirty Two showing the flood heights and levees of slash (arrowed) adjacent to the stream discharging from the Willowbank forest.

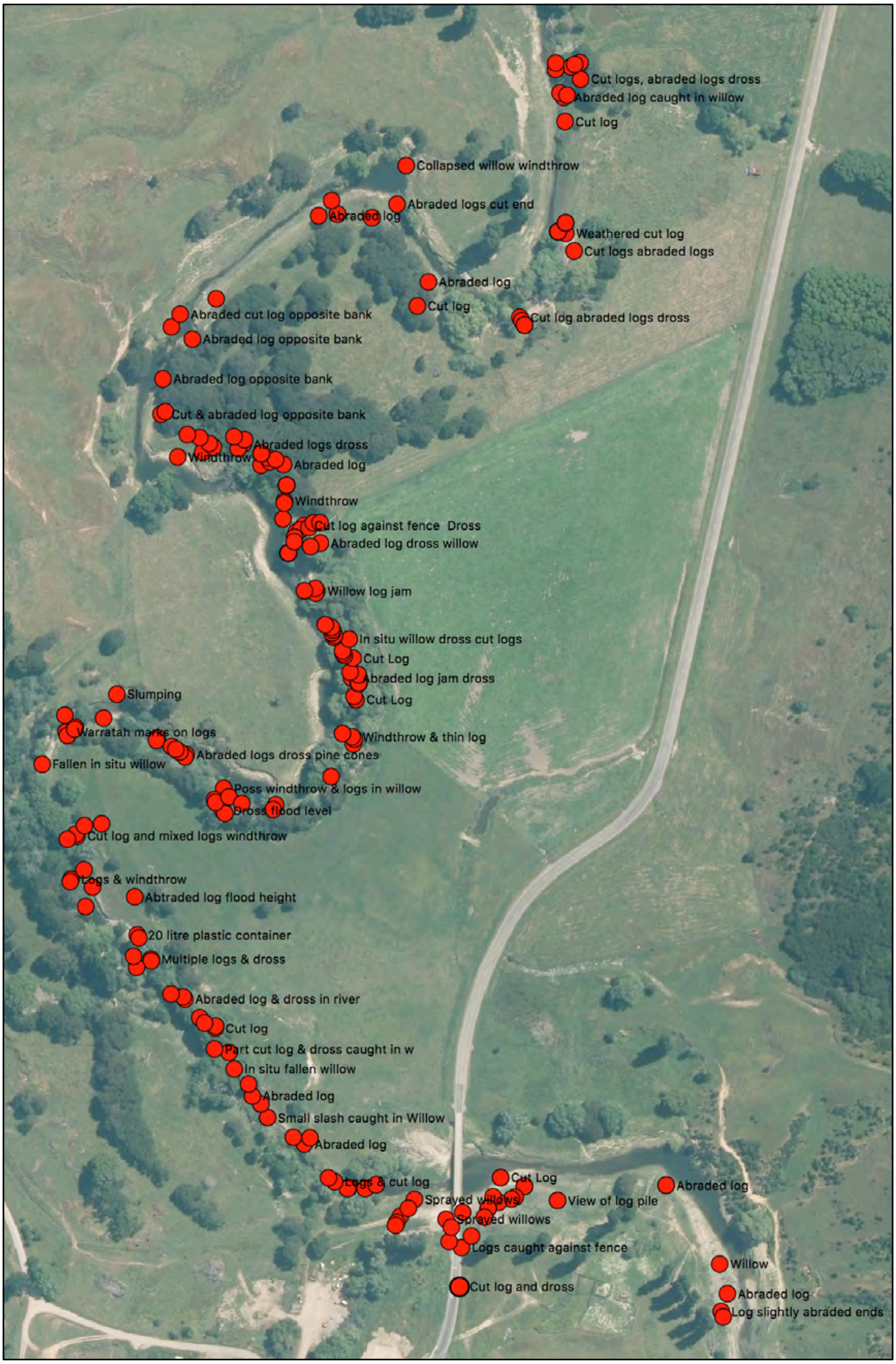

Figure 79. Annotated aerial imagery of the Mangaheia River from below Willowbank Forest to Wigan Bridge showing the location of geo-referenced photographs with descriptions of the woody material seen at each location.

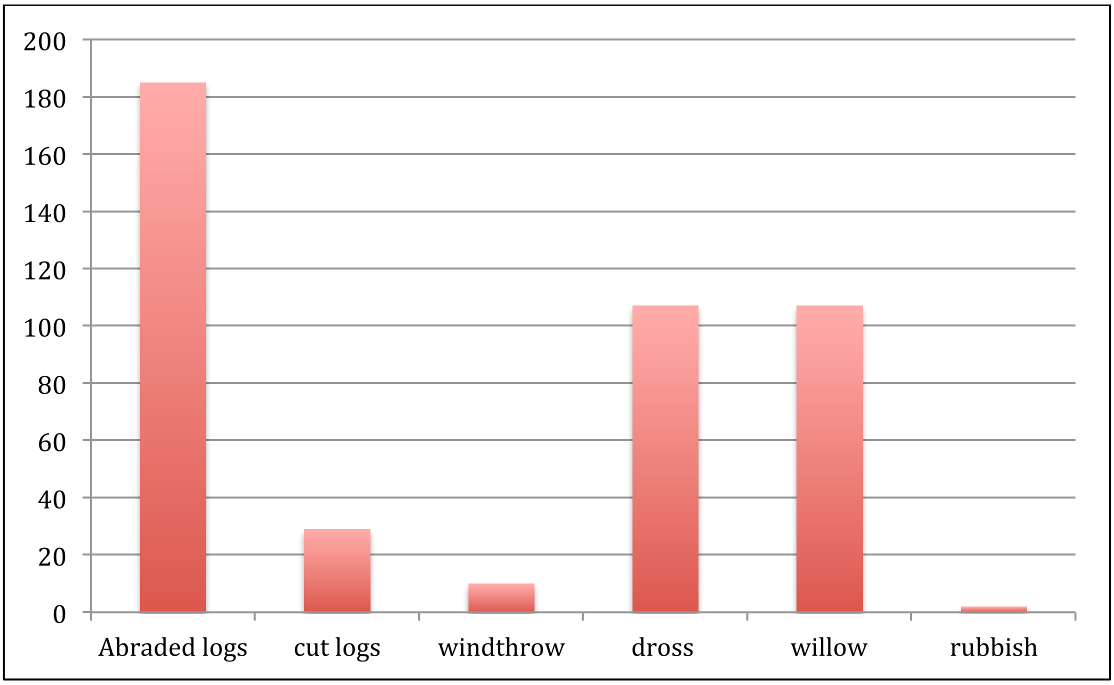

Figure 80. The proportions of the various types of woody debris counted in the river upstream from Wigan Bridge.

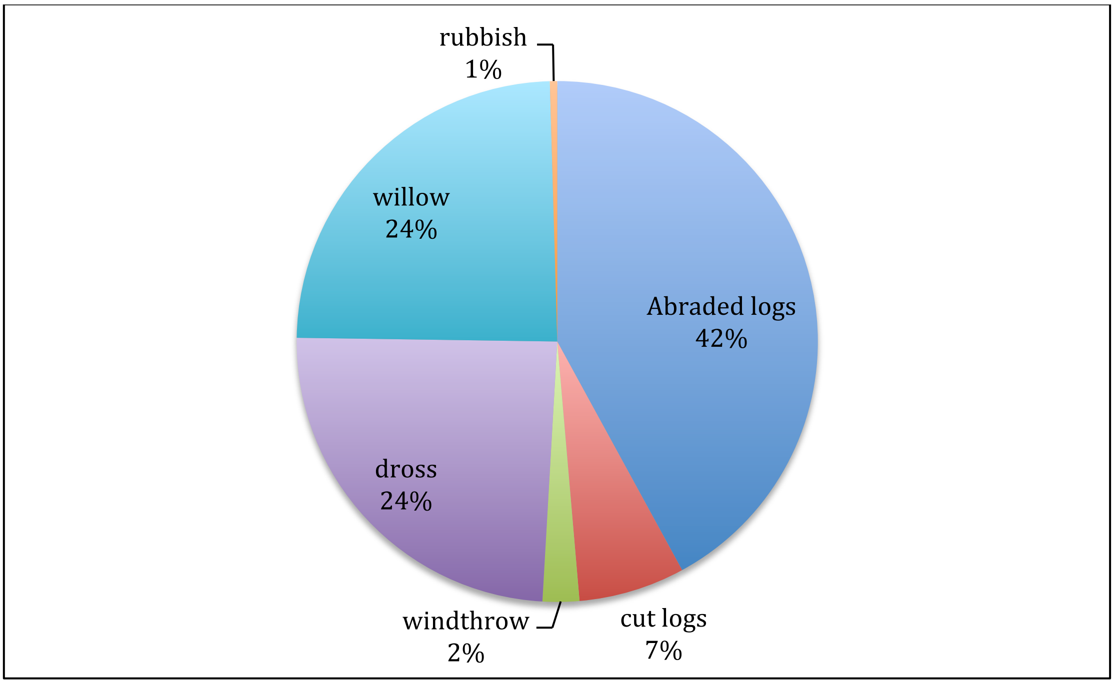

Figure 81. The same data as in Figure Eighty calculated as a percentage. Overall, pine material comprised 51% of the total woody debris counted.

Figure 82. Accurately counting the material within a large slash pile can be difficult. This pile contains both pine and willow and a lot of "dross".

Figure 83. Abraded pine logs above Wigan Bridge with Waratah markings.

Figure 84. Fresh cut log caught up in willow above Wigan Bridge on the Mangaheia River.

4.2.1.6 Wigan Bridge

Wigan Bridge was significantly affected by Cyclone Cook with a lot of debris caught up against the bridge putting it at risk of failure. Flood waters overtopped the bridge as a result of the debris dam and some slash was distributed along the road.

After the event, Tairiwhiti Roads undertook emergency clearance at the bridge and the debris was put into three piles while more material was released into the river. The material observed downstream of Wigan Bridge during the overflight (see Figure 35) is inferred to have been released from the bridge. This material was no longer present when inspected on the 14th of May and would have ultimately ended up on Tolaga Bay Beach (see below).

From an initial inspection, all 3 piles contained a mix of material with cut logs, a few withthrow logs, and abraded logs particularly along with some willow and dross/mud, but an accurate quantification of the material within the piles was impossible as a result of the incorporation of bank material in the slash piles (*Figure 85*). As a result, it was decided that the only way that the material could be accurately determined was to deconstruct the slash piles with a digger (*Figure 86*).

The analysis of the deconstruction showed the presence of some cut logs including some fresh clean cuts and some partially abraded cut logs. While many of the abraded logs may have originally shown cuts, a high residence time in the river system had abraded the ends so that these tended towards a conical or irregular shape. A pie chart shows the total proportions of each type of material is shown in

Figure 87. Looking at the data in each pile (*Figure 88)*, some variations can be seen but this is clearer when the data is recalculated on a percentage basis (*Figure 89*).

Figure 85. View of the northern most slash pile at Wigan Bridge prior to deconstruction. The process of pulling the slash from the river resulted in riverbank material being included in the piles.

Figure 86. A digger was used to deconstruct the slash piles so that the material could be quantified.

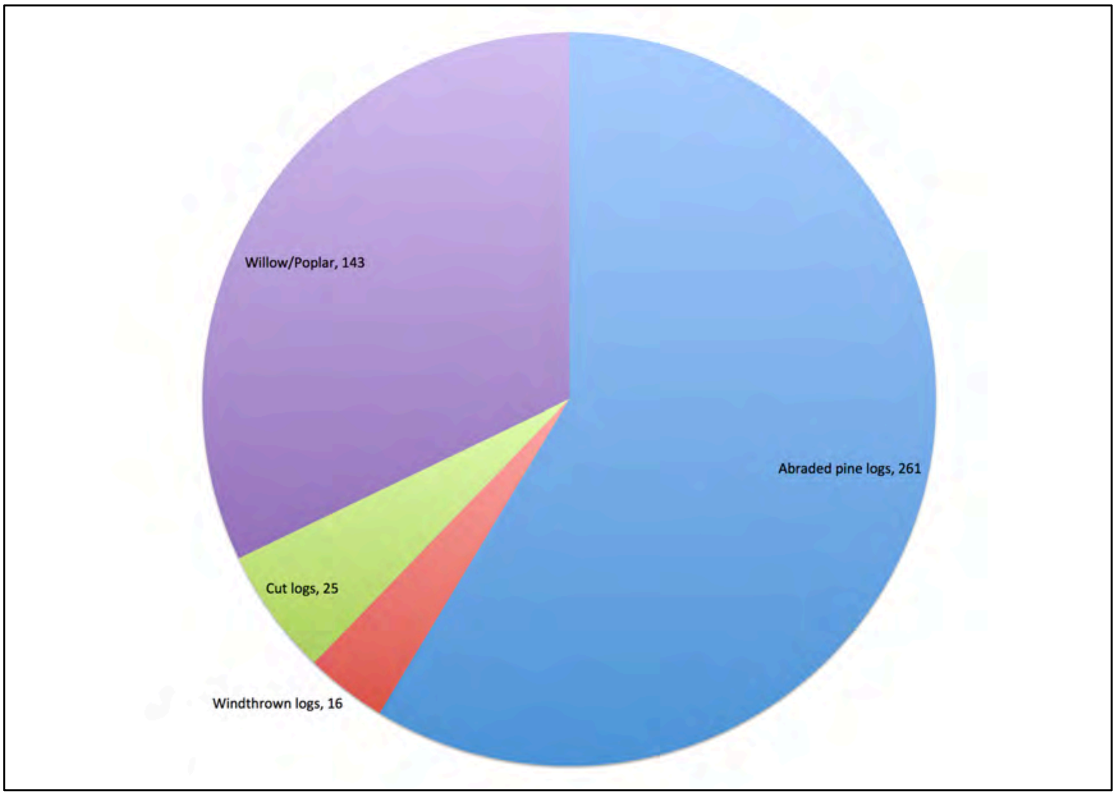

Figure 87. Pie chart of total numbers across all 3 piles. This shows that much of the material was pine logs of some form or other while the rest comprised willow or poplar.

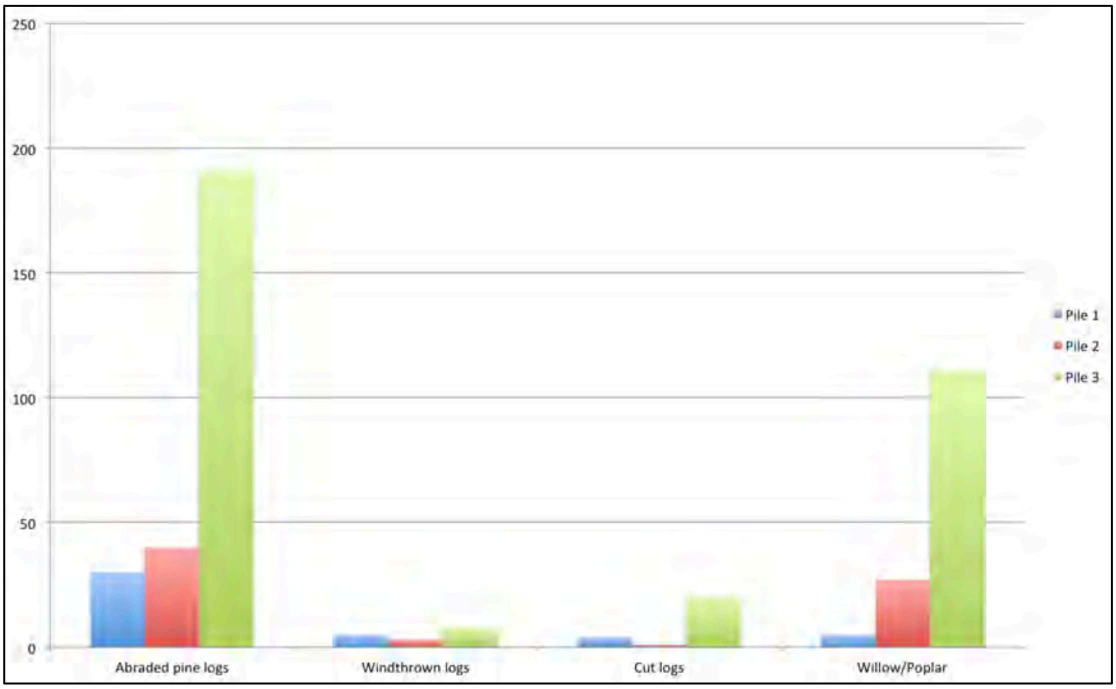

Figure 88. Log types broken down by slash pile.

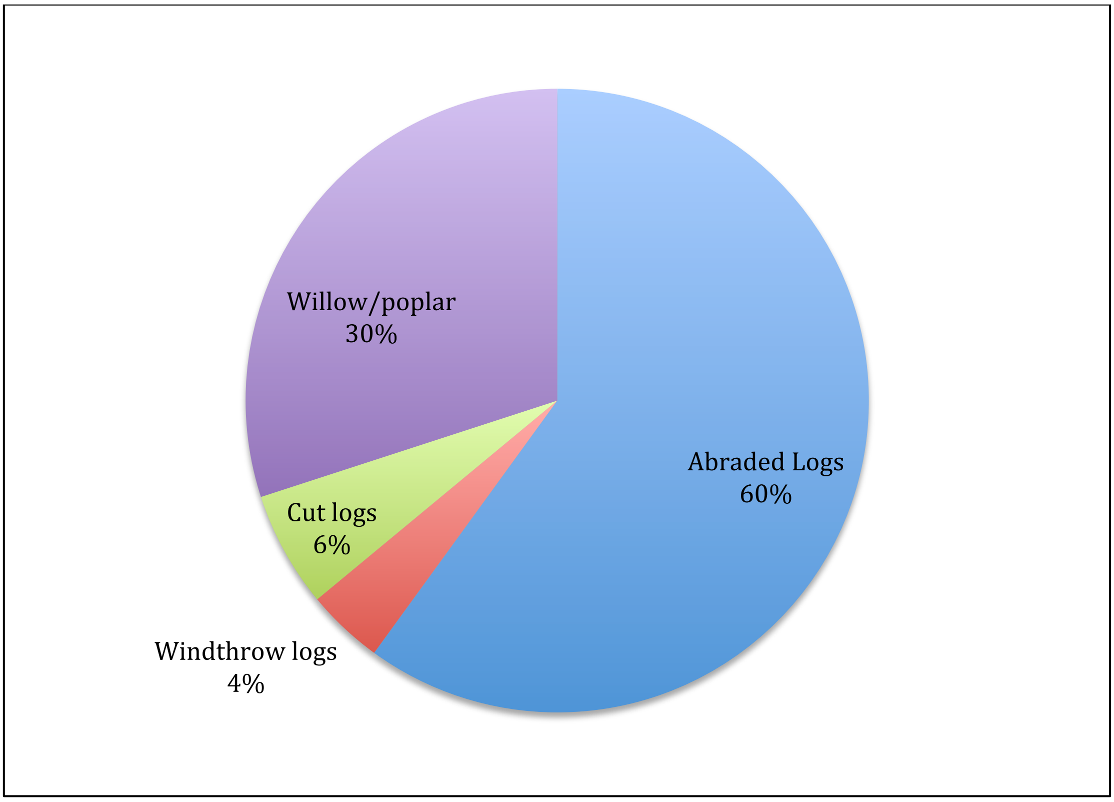

Figure 89. Woody debris type aggregated for all sites expressed as a percentage.

There are some key findings. Firstly, the dominance of abraded logs is evident but the small number of windthrown logs was a surprise as it was acecdotally suggested that much of that material left on the slopes was windthrow and this would increase the chances of these entering the fluvial system. The proportion of windthrow vs unrecovered cut logs on slopes has not been quantified in this study but an assessment of the imagery collected suggests that the role of windthrow has been overstated. The relatively high number of cut logs, some quite fresh, was unexpected and while some may have been derived from the failed crossing at Willowbank Forest, the numbers are too great for this to account for all cut logs.

The proportion of willow/poplar wasn't evident in the visual inspection of the piles prior to their deconstruction. The amount of willow is particularly evident in pile three and was relatively under-represented in the downstream pile suggesting that it was preferentially captured by the slash dam at the bridge. It may be that during the flood, the influx of pine initiated the failure and resulted in the mobilisation of the poisoned willows upstream of Wigan Bridge.

The most critical finding is the dominance of abraded logs. Based on the upstream inspections we know that not all of the debris reached the Wigan Bridge. Further, it is estimated that at least the same amount of debris is now caught on the flood plain above the bridge and is vulnerable to mobilisation in a future event. These logs have clearly had a significant period exposed to abrasion within the river system. Thus it is possible that a significant proportion of the material caught in the Wigan bridge dam at Easter was debris from a prior event distributed along the banks of the river and thus at risk of mobilisation during this event.

Equally, the identification of an equal amount of material in the flood plain upstream of Wigan means that another event would result in a similar slash dam even if no new material was supplied from an area of active forestry. This does not mean that no new material (other than at the Willowbank crossing) was introduced by current forestry activity. There is evidence that material was mobilised at Mangatoitoi and Everets Road and even if not all of it reached Wigan bridge it is now in the river and vulnerable to mobilisation in a future event.

The significant contribution of willow at this site and upstream was initially a surprise as there was no obvious source. Meetings with some local landowners provided some clarity when they advised that the willows adjacent to their property had been sprayed several years previously. These had died and from my observation at least one in the vicinity of their property had failed and was at least partially within the river system. The inspection upstream of Wigan showed that many of the willows there were dead and while most were intact it was entirely possible that some had fallen over due to becoming rotten or riverbank collapse. The landowners subsequently contacted me with information which confirmed that the willows were sprayed by council. Enquires established that the spraying was undertaken on behalf of Tairawhiti Roads.

The investigation in the Mangaheia indicates that in the future the problems associated with both dead willows and the pine logs resident within the river system need to be addressed.

4.2.17 Mangatokarau

The impact of Cyclone Cook in the Mangatokerau catchment were significant with slash being deposited downstream of the active forestry areas and one dwelling under threat from waterborne slash. These impacts had been summarised in sections 3.1.2 and 3.4.7 above.

The overflight on the 21st April 2017 showed that there was one debris flow on the true right side of the river from an unnamed stream between Makawakawa and Te Kokokakahi Streams. For the purposes of this report, this creek is referred to as Waterfall Creek. This was the probable source of some of the slash in the river downstream. A field inspection was subsequently undertaken with the forest managers who suggested that the debris flow was the primary source of the debris. Analysis of the geo-referenced photographs collected during the overflight along with the field inspections did not provide confidence that the debris flow was the only source for the slash mobilised within the catchment. An inspection was therefore undertaken on the 30th of May to assess all of probable sources for the slash mobilised during Cyclone Cook in the Mangatokerau catchment.

Geologically the area has a similar rocktype to the Doonholm Landslide in the Upper Tauwhareparae with much of the area underlain by undifferentiated Middle to late Miocene homogeneous to bedded, grey slightly calcareous mudstones of the Tolaga Group (*Figure 90*). The debris flow in Waterfall Creek occurred on the boundary of the undifferentiated Miocene mudstones with bluff-forming muddy and shelly sandstones of the late Miocene Tokomaru Sandstone. Several poorly defined faults cross the area although none are mapped close to the area of failure. In other ways, however, the Waterfall Creek debris flow is similar to the Doonholm Landslide since the north east to north facing aspect is similar and both occurred on class 7e15 land. The Waterfall Creek landslide differs in that it was triggered adjacent to an abandoned landing and the overall slope angles were less than for Doonholm.

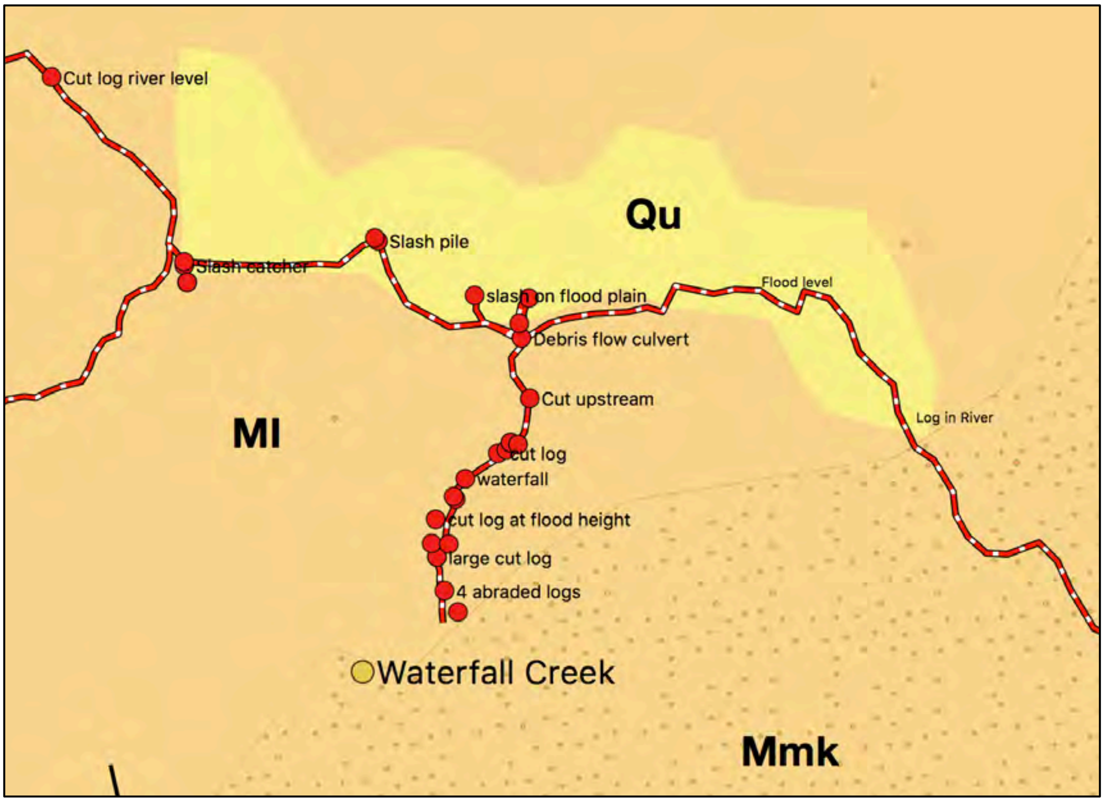

Figure 90. Generalised geology of the Mangatokerau Valley showing the location of the debris Flow trigger point (Orange circle), the different Miocene (MI, Mmk) and Quaternary (Qu) lithologies, and the route taken during the investigation and geo-referenced points.

Although the debris flow at Waterfall Creek was an obvious source of debris in the Mangatokerau, the over flight results suggested that stowage of slash on the floodplain was widespread within the catchment (see *Figures 91* and *92* below). Not all areas could be visited but a traverse was made up a road rising from the true left of Te Kokokakahi Stream so that a current operating area could be safely assessed from above. This was an area where imagery from the flight indicated significant slash in gullies and slopes vulnerable to mobilisation during storm events. In the end, little more could be seen above the valley than was shown in the aerial imagery.

The base of Te Kokokakahi Stream itself was more relevant. The road crossed the stream at a culvert which showed the trim lines and silt deposition typical of a flood event in the stream. Close to the stream on the true right hand side, a couple of cut logs along with the remains of a slash catcher were observed (*Figure 93*). A short distance up the stream a collapsed willow had formed a natural slash catcher which had a bird's nest of fine dross and logs caught up against the upstream side including cut logs (*Figure 94*).

Figure 91. Typical situation with scattered slash on the flood plain in the Mangatokerau River.

Figure 92. Extensive scattered slash on the Mangatokerau River flood plain.

Figure 93. View of cut logs and a failed slash catcher at the base of Te Kokokakahi Stream.

West of Te Kokokakahi Stream, the main forestry road climbs gradually around the hill following the Takamapohia Stream. At the first ford crossing the river at a location known as Staircase, recent flood sediment along with mobilised pine logs banked up on the bank in the river was observed. Accordingly, the area beyond the ford was traversed to see if any debris flows that could have contributed material to the river could be identified. No evidence of mass movement was seen and much of the area had not yet been harvested although there are some areas of harvest above Staircase in the catchment (*See figure 44 above*).

Figure 94. View of collapsed willow a short distance up Te Kokokakahi Stream with fine dross and high silt load, and an obvious cut pine log on the middle right of the photograph.

A number of geo-referenced photographs were taken and shown in *Figures 95* and *96* below. *Figure 96* shows mud and soil piled on top of the pine logs in a way that suggests placement in a post-flood clean-up, however, no forestry company incident report was received about this area despite such incident reports being requested.

Figure 95. View of the ford at Staircase showing considerable silt deposition and logs caught up in the bend of the stream above the ford.

Figure 96. View of the ford at Staircase showing the log pile, significant silt deposition, and post clean-up silt piles.

The debris flow fan at Waterfall Creek was then inspected. Because the area had already been cleaned up, the character of the depositional zone could not be fully assessed but there were indications of trim lines and levee deposits suggesting a considerable volume of material was involved. The adjacent slash piles were notable for the presence of numerous cut logs as well as logs with broken ends (*Figure 97*). Waterfall Creek was then traversed for as far as it was safely practicable (*Figure 98*) with all logs within the traverse area photographed and geo-referenced.

Figure 97. View of slash pile at Waterfall Creek showing a cut log as well as broken pine logs

The key finding of the traverse was that a significant proportion of the logs within the stream were fresh cut pine logs showing little sign of weathering (*Figure 99*). There was no contribution from species other than pine which is to be expected in a plantation forest. There was also only minor fine sized dross which suggests that the debris flow comprised large volumes of water relative to the sediment available for transport. Overall nearly 30% were fresh cut logs and there was an equal amount of weathered logs with cuts and weathered logs with no evidence of cuts respectively at 26% for each class (*Figure 100).*

An incident report on the waterfall Creek debris flow was provided by the forestry company operating in the area but this did not provide enough detail on the mechanisms of failure at the source. What is clear from the data from the creek and the overflight is that the debris flow originated adjacent to a landing on Spencer Road and that both stored and fresh potentially merchantable cut logs were involved in the debris flow. An example of the type of material in the creek is shown in *Figure 101* below and additional images are shown in **Appendix One**.

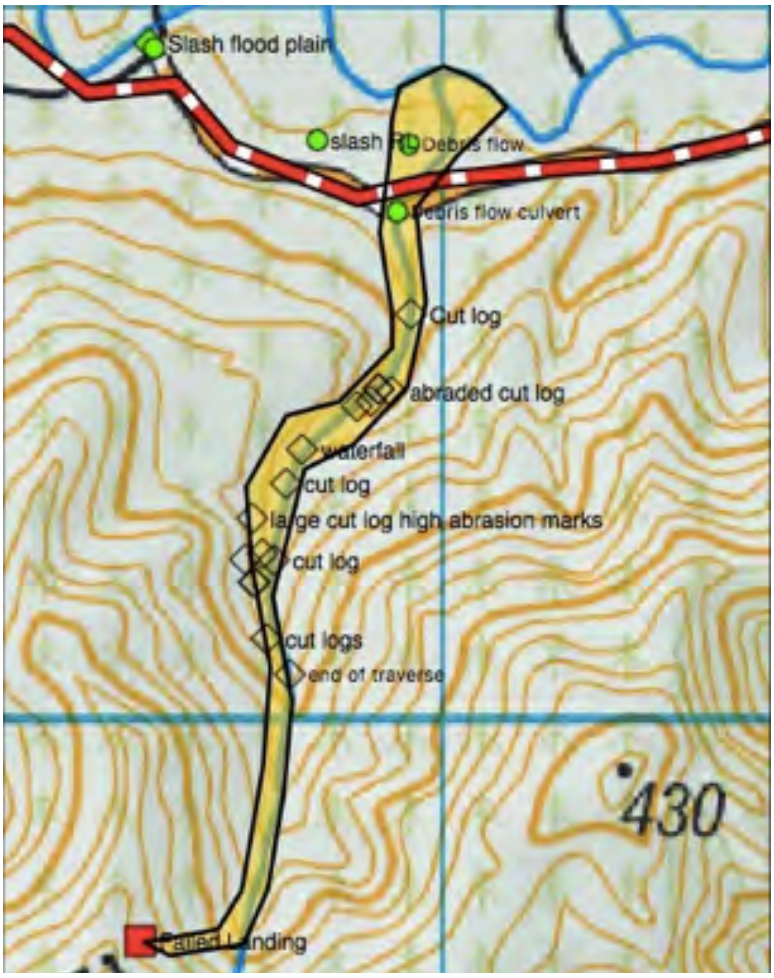

Figure 98. Map of Waterfall Creeek showing the debris flow origin (Orange box) adjacent to the landing and geo-referenced observation site in and adjacent to the creek.

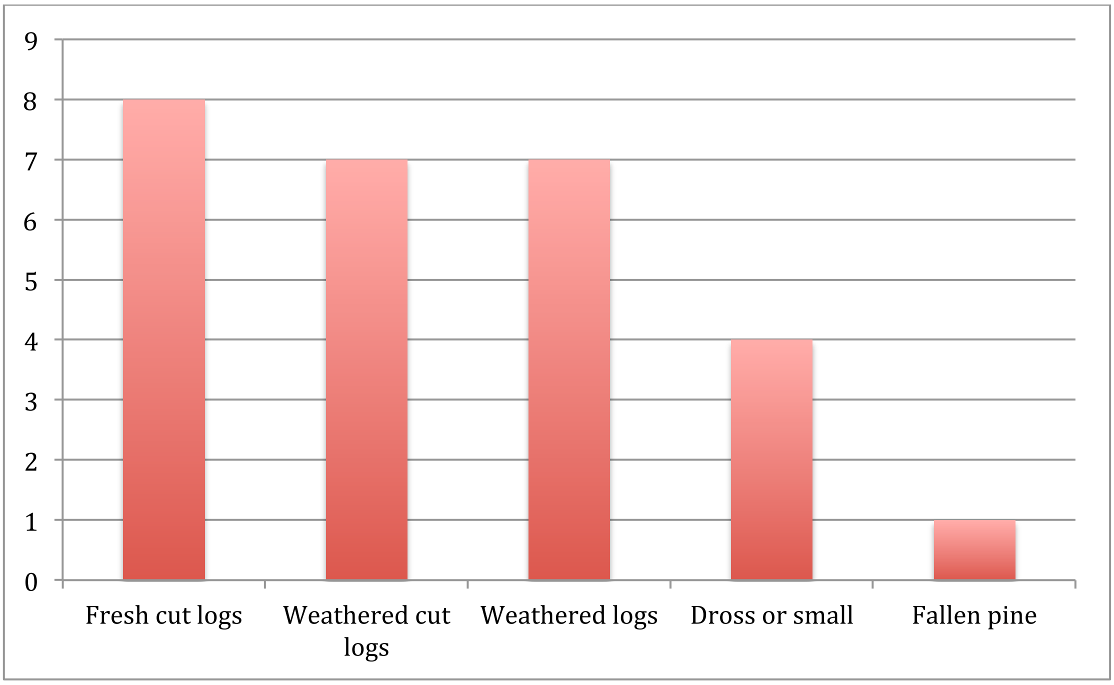

Figure 99. Plot of the types and proportion of pine recorded in Waterfall Creek.

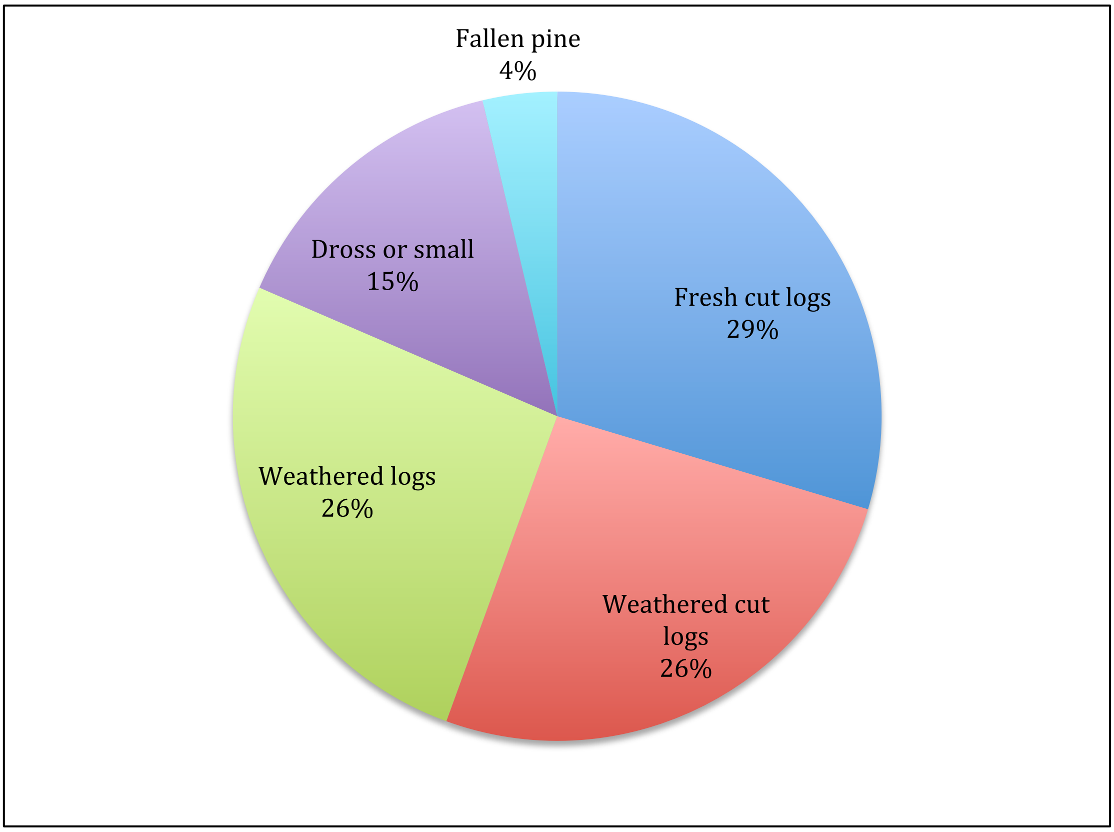

Figure 100. Pie chart showing the pine types expressed as a percentage.

Figure 101. Example of a fresh cut log wedged on a tree at debris flow height, Waterfall Creek.

The key conclusions from the Mangatokerau catchment study is that there were multiple sources of slash in the catchment (Staircase, Te Kokokakahi Stream) rather than just the debris flow in Waterfall Creek, which was significant. In addition, the observations at Te Kokokakahi Stream indicates that slash was mobilised from operational areas during the event. The presence of remains of a slash catcher at Te Kokokakahi Stream and the level of silt deposition at the culvert indicates a sizable event in this catchment. This is not surprising given its proximity to Waterfall Creek. A number of other streams within the catchment such as Takamapohia stream also showed signs of either slash mobilisation or significant areas of slash on flood plains at risk of mobilisation during a flood event.

4.2.1.8 Tolaga Bay Beach

The Tolaga Bay beach is the ultimate receiving environment for slash mobilised in the Uawa Catchment and it is a contentious issue for locals and the wider community because of the beach's values as a tourist destination.

The study had two objectives; firstly to allow for an empirical evaluation of the mix and quantities of woody material on the beach to support a visual assessment undertaken earlier. Secondly, to initiate a citizen science project with Tolaga Area School as a pilot for further school-based science projects in Tairawhiti district. The citizen science day was carried out on the 22nd of August using 18 students in 12-13 year and 16-17 year cohorts, supported by GDC science staff, and the school teachers and helpers.

While it would have been ideal to survey the entire beach this was not achievable for three reasons. Firstly, the material close to Tolaga Bay wharf had been moved mechanically to provide tractor access to the beach and the material south of the wharf had also been subject to significant winnowing due to tidal surging since Cyclone Cook. Finally, the resources requires to identify and count every log on the beach was unsustainable.

Instead, three 10x10 metre plots were put in at roughly equidistant points along the beach and every piece of woody material over 6cm in diameter were counted within the plots. Logs that were largely outside the plots but with ends falling within the plots were not counted while logs at least 75% within the plots were counted. The location of the plots is shown in *Figure 102* below. Each plot was geolocated and photographed to record the location for possible later re-occupation. The location of the sites assessed qualitatively earlier are shown in *Figure 103*.

The students were provided with a photographic guide to assist them identify the different types of material using the types identified during the earlier qualitative assessment (**Appendix Two**). The types of material are as follows;

Cut Pine logs; Pine logs with cut ends where the degree of weathering of the cuts is consistent with the weathering of the log overall and show little abrasion. These can show signs of being through a de-barker.

Long Resident Pine logs; These are logs similar to above but where the cut ends have been abraded and worn due to the period they have spent in the river. These ends can be still at right angles to the log but over time can be worn to a cone shape.

Fresh Cut Pine logs; These are logs that have a fresh cut inconsistent with the level of overall weathering. These logs represent either of the above but have been cut by locals obtaining firewood.

Willow/Poplar; Woody material distinguished from pine by branching characteristics, bark texture, and trunk shape. Even where the trunks were straight they can be differentiated from pine by having a spiral rather than straight grain in the trunk.

Windthrow Pine log; Pine with characteristics of cut pine or long resident logs but with a root ball at one end.

Windthrow Willow/Poplar; As above but with characteristics of willow or poplar.

Figure 102. Location of the three 10m^2 Slash plots on Tolaga Beach.

The raw results of the survey are shown in Table 4 below. The initial key finding of the assessment was that there was a marked variation along the beach with the middle plot being an outlier recording significantly more willows and poplars than the other sites. While this may have been a correct count, the counters may also have misidentified some logs. Since all the logs counted have been sprayed with dazzle, a double check of the recording was undertaken to verify the results. This indicated that a miscount (pines with a straight grain counted as willow) had occurred and the data below is the corrected value.

Figure 103. GPS locations of photographs taken on the 15th of June 2017 (red dots). Two photographs are located at the south and middle plot sites and can be used to assess any movement of woody material between June and August.

	South	Middle	North
Cut Pine log	10	3	13
Long Resident Pine log	44	56	24
Fresh cut pine log	0	1	2
Willow/Poplar	15	24	15
Windthrow pine	10	7	5
Windthrow willow	17	3	8

Table 4. Raw data for the Tolaga Bay Slash investigation showing the number of logs over 6cm diameter within each 10m plot.

This data was then plotted as a bar chart showing the different types of woody material defined by plot and expressed as a percentage (*Figure 104*).

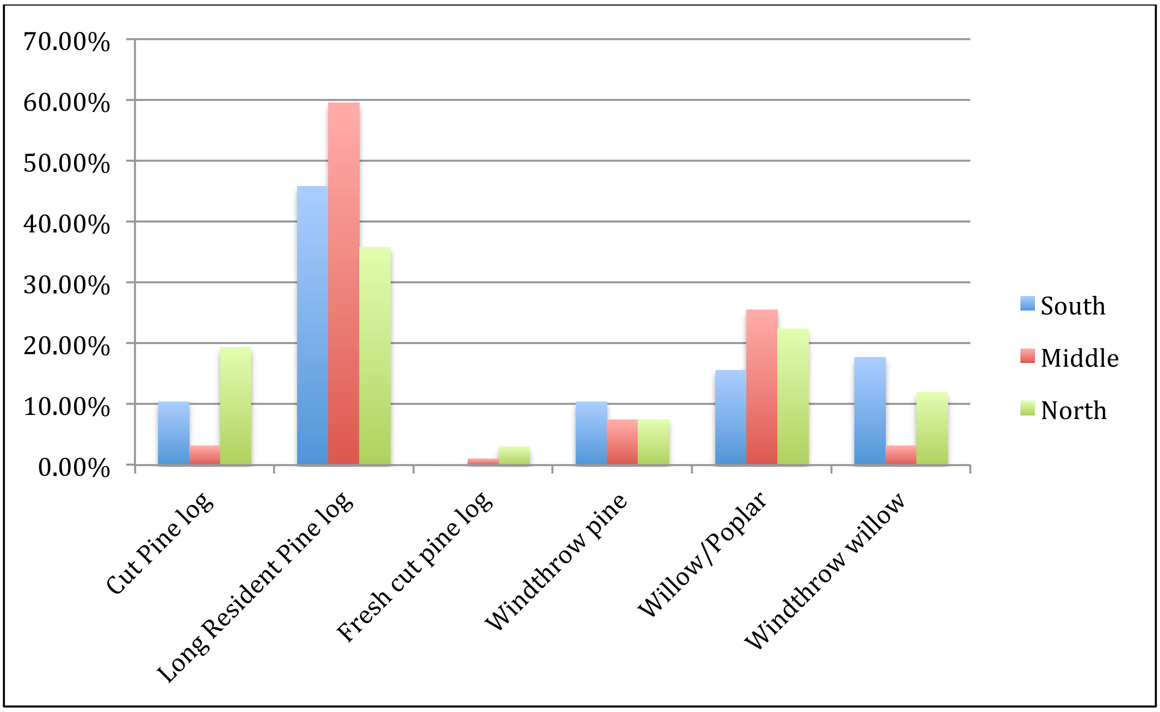

Figure 104. Plot of the data from Table Four showing the contrast in woody debris types between the plots expressed as a percentage .

The data was then aggregated as all pine vs all willow and poplar, firstly by plot and then aggregated as all pine vs all willow and poplar. This shows that pine was twice as common as willow and poplar in all plots (*Figure 105*). Once aggregated further it is clear that pine outweighs willow and poplar combined significantly (*Figure 106*).

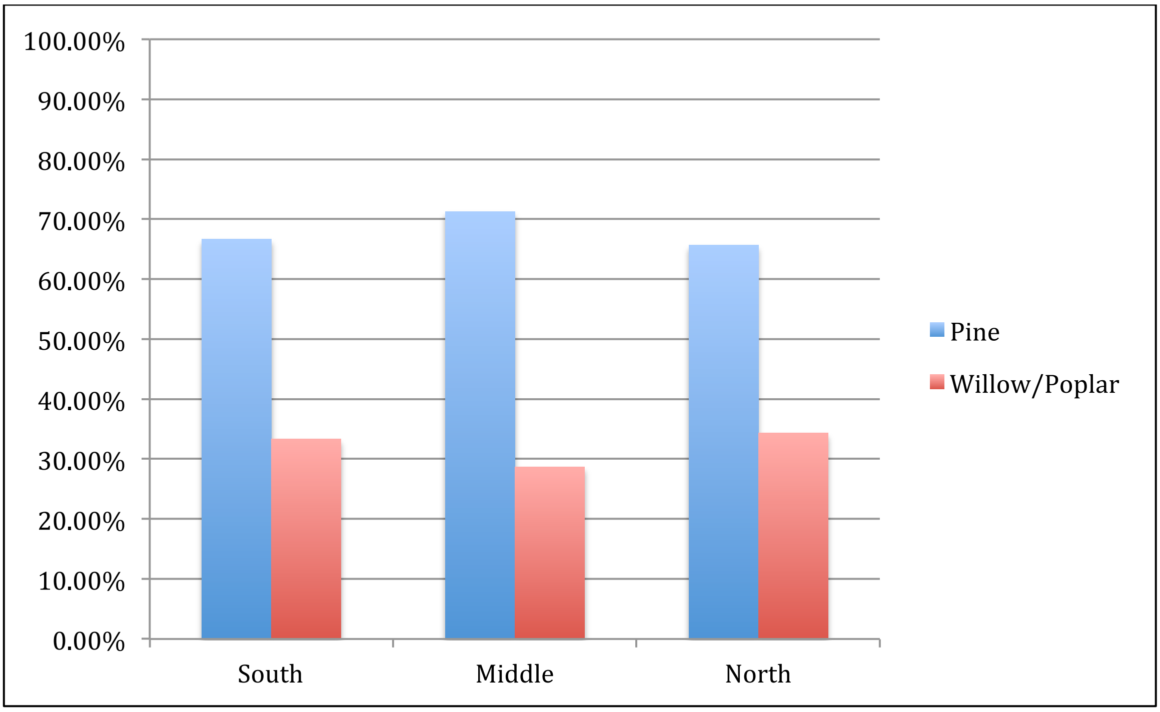

Figure 105. Percentage Pine vs Willow and Poplar by plot.

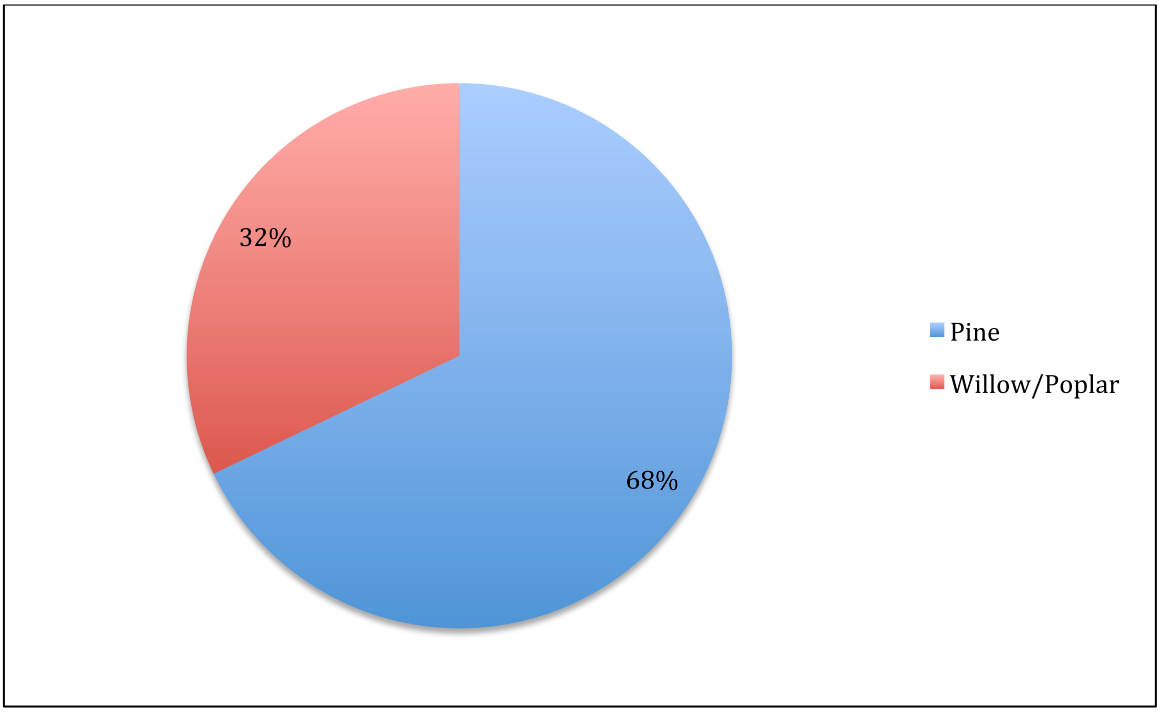

Figure 106. Percentage of Pine vs Willow and Poplar aggregated across all three plots.

The study shows that the Tolaga Beach is a receiving ground for a variety of woody material with pine logs more common that willows and poplars. Compared with the slash piles at Wigan Bridge; willow and poplar is slightly more common reflecting the available source catchment for willow and poplars planted on the riparian margins of the Uawa River catchment below either the Mangaheia and the Mangatokarau rivers. Of note was the absence of indigenous material with only one readily identifiable indigenous log observed.

The types of pine log materials present is also significant with 88% of all pine being pine logs that have been either or partially fully processed and only 12% being windthrow (*Figure107*). As was the case at Wigan Bridge, long resident-time pine logs are the most common. The presence of these weathered processed logs with abraded cut ends indicates two things. Firstly, it indicates that there is a significant population of pine logs present (resident) in the river systems and available to be mobilised during extreme rainfall events. Secondly, as has become apparent in the overall investigation, there are a number of slash piles within the operational forest areas that are vulnerable to mobilisation during flood events.

What has also become evident is that the degree of visible greying of the wood is, in itself, a poor indicator of age of the log. This is highlighted by *Figure 20* in **Appendix Two** which shows a grey weathered log but which also shows the remains of a forestry company's paint mark on the cut end. Much of the literature on the decay rates of Radiata are long term studies looking at decay rates at 0, 5, 10, and above yearly rates rather than in the first months and years after milling (Garrett *et. al.* 2008). Other studies indicate that the time between harvest and processing is critical to timber quality. The conclusion is that greyed timber without surface degradation but with sharp cut marks or visible waratah marks is likely to be only a few months old. Older logs then lose the grey colour and fade to a creamy white colour.

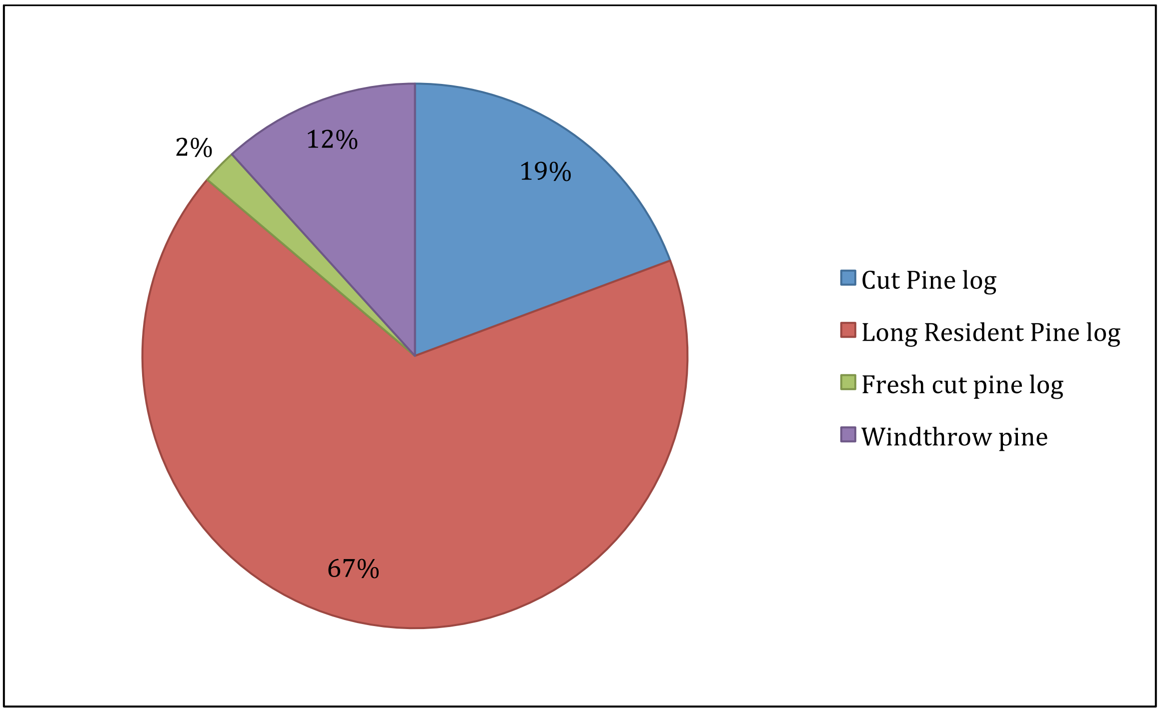

Figure 107. Proportion of the various types of pine wood on Tolaga Beach. Calculated for windthrow vs fully or partially processed pine (fresh cut pine, cut pine and long resident pine), the proportions are 12% windthrow vs 88% processed or partially processed.

4.2.1.8.1 Tolaga Pre and Post Cyclone Cook

On the 28th of January 2017 a photograph of Tolaga Bay Beach from the Wharf was taken to demonstrate the then current state of woody debris on the beach (*Figure 108*). This image shows residual slash which according to the local community was deposited in 2015. In front of that is a band of vegetation and in front of that again is a line of small woody material (dross). The same point on the wharf was then re-visited on the 11th July to examine the impact of Cyclone Cook on the beach (*Figure 109*).

This demonstrated that there had been a significant change in the volume of distribution of woody debris on the beach between the 28th of January and July 2017. A record of the photographs taken in June and July 2017 has been incorporated in this report as **Appendix One**

Figure 108. Photograph of Tolaga Bay Beach taken at 11:49AM, 28th of January 2017.

Figure 109. Photograph taken from approximately the same point as Figure108 showing the extent of deposition of additional woody debris as a result of Cyclone Cook.

The data obtained on the 11th of July shows that the largest population of woody material comprises long resident-time pine logs that have been subject to decay and erosion of cut ends over a period of time but fresh greyed but unweathered cut logs were also present. Overall pine woody material outweighs willow and poplar debris, and the distribution of pine material vis willow and poplar is similar to that recorded by the Wigan Bridge study.

4.3 Waiapu Catchment

The Waiapu Catchment is one of the larger catchments in Tairawhiti and is also recognised as having the highest sediment load of any river in New Zealand (Hicks *et al* 2011). It comprises two large sub-catchments, the Mata and the Tapuaeroa, and the Cyclone Cook slash investigation has focussed on the Whakoau River within the Mata sub catchment.

4.3.1 Whakoau Rver

The Whakoau River tributary of the Mata River was the only river within the Waiapu Catchment where enough information was available to undertake a detailed assessment of the impacts of forestry slash. A operational landing at the beginning of River Road off the Mata Road was visited on the 13th of December 2016. It was noted that the landing was close to river level at broad loop in the river and would thus be vulnerable to flood events (*Figure 110*).

Figure 110. View of landing on the Whakoau River, bottom of River Road, Mata 13th December 2016 showing the landing with stored logs on the flood plain.

The landing is located on a flat portion of the Whakoau River and is approximately 1 to 1.5m above normal water level in the river and relied on a slash catcher immediately downstream to protect the river from slash mobilisation (*Figure 111*).

Figure 111. Aerial image of the bottom end of the Whakoau River on River Road showing the location of the forestry landing on the river flats on the true right side of the river. Also shown is the position of the slash catcher downstream of the site.

The slash catcher was visited on the 24th of April and allowed the impact of Cyclone Cook on the river to be assessed. It was obvious that a considerable amount of woody debris had mobilised upstream of the slash catcher (*Figure 112*). The slash catcher itself had failed (*Figure 113*) and as a consequence much material migrated downstream and entered the Mata River. Some pine slash has been found at the Ihungia Bridge on the Mata but not at Ruatoria or on the beach at Tikitiki.

Figure 112. Looking upstream from the slash catcher towards the landing showing the debris and high silt load mobilised during Cyclone Cook.

Examination of the failed slash catcher on the 24th of April visit revealed that even on the true right bank where the catcher had not failed, it had still been overtopped by woody debris (*Figure 114*).

Figure 113. View of failed slash catcher and forestry slash caught on the river bank.

Figure 114. View of the slash catcher in the Whakoau River at the beginning of River Road. In the background are logs that overtopped the slash catcher, and in the foreground are logs that had been arrested by the catcher. It is clear that the material caught against the catcher comprise cut pine logs as well as smaller dross but no willows, poplars, or wind-throw logs and considerable silt deposition.

A series of photographs were taken of the area during the over flight in April and the open nature of the catchment meant that the imagery acquired were valuable for determining the behaviour of the Whakoau event . These show that a considerable amount of forestry slash was present on the flood plain and within the active channel of the river after Cyclone Cook but no landslides were identified.(*Figures 115, and 116)*.

Figure 115. View of the Whakoau river upstream of the failed slash catcher showing slash caught against the river bank on the true left, within the river channel (middle background) and two areas of slash stored on the flood plain.

Figure 116. View of the slash catcher site and the area immediately upstream showing slash stored on the flood plain on the true right bank of the river.

One further photograph taken further upstream and looking down towards the slash catcher indicates that the river upstream of the area shown above is now largely free of slash but this may indicate that it had been swept clean during the event. The side stream on the true left does, however, show some material that is clearly in a vulnerable position and at risk of mobilisation (*Figures 117 and 118*).

Figure 117. View of the Whakoau River showing the main channel clear of slash above the area shown in Figure 116 although the side stream in the foreground does have some material at risk of mobilisation.

Figure 118. Detailed view of the side stream shown in Figure 117 showing material adjacent to and in the watercourse.

Since the visit on April 24th and the over flight indicated that slash had been mobilised during Cyclone Cook, the area was revisited on the 11th of July to assess whether or not there were any indications of mobilisation of the slash piles on the flood plain. The eastern end of the flood plain showed clear signs of flooding with new silt deposition and vegetation bent over by the flow of water (*Figure 119*).

A view of the eastern end of the slash pile is shown in *Figure 119* and in closer detail in *Figure 120* below. While a comparison with the aerial imagery shown in *Figure 112* indicates that some remediation of the slash pile has occurred. It also shows clear signs that the material to the right of the track was exposed to floodwaters and that the slash was most likely mobilised during Cyclone Cook.

A visit on the 29th of August showed that a new slash catcher had been installed and despite the lack of any significant recent storm events, the catcher was collecting new slash including fresh cut logs (*Figure 121)*. A further fresh cut log was stranded on the river bank immediately upstream (*Figure 122).*

Figure 119. Eastern end of the flood plain immediately upstream of the slash catcher showing silt deposition and vegetation bent over by floodwaters.

Figure 120. View of the landing showing the extensive silt deposition within the slash pile and the clearly demarked trim line. Note the cut logs above the trim line.

Figure 121. View of the Whakoau River showing the new slash catcher with recently collected logs including fresh cut logs.

Figure 122. Fresh Cut log with paint mark in the Whakoau River upstream of the new slash catcher.

The observations at the Whakoau indicate that slash mobilisation was the result of slash stored on landings very close to river level being overwhelmed by flood waters during Cyclone Cook. The post event over flight and site inspections found no evidence of landsliding in the catchment.

5.0 Analysis

5.1 Previous work

Cyclone Cook was not the first post tropical cyclone to hit the Tairawhiti District and it won't be the last. Cyclones have had a profound impact on the landscape of the region, most particularly Cyclone Bola in 1988 which hit a landscape then dominated by pastoral farming. The result was widespread slope instability and mobilisation of soils and soft sediment to the region's river systems. After Cyclone Bola, the government supported the region in embarking on a programme of widespread planting of exotic forests to stabilise these vulnerable slopes (Parliametary Commissioner for the Envronment 1988, 1994). But with these forests now ready to harvest has come the problem of slash mobilisation in the forests of Tairawhiti.

Tairawhiti is also not the only region with problems with forestry slash. A storm in the Marlborough Sounds in early November 1994 resulted in eight landslides in an area that had been harvested over the previous few months. The storm was not particularly intense compared with what the area can receive but the damage was locally significant. It was observed that slope failures in forested land will be an issue during intense rain events and that harvest on slopes of 30° will need to be managed in a way that it does not seriously disturb the soil (Phillips, Pruden and Coker 1996). Baillie and Evanson (2014) reported on the impacts of a "1:100 year" event within an area of recently harvested forest adjacent to intact indigenous vegetation in the Coromandel in 2014. The event caused widespread damage including extensive mid slope failures and gully erosion and this had a flow on impacts indigenous vegetation downstream. The study focussed on riparian and in-stream impacts and the rate of recovery in indigenous vegetation rather than slash mobilisation issues in and beyond the forest.

In a 2011 review of erosion susceptibility and erosion risks in plantation forests, Bloomberg, Davies, Visser, and Morgenroth (2011) noted that in general, landslide erosion risk (hazard) is higher under more intense rain. They also noted, however, that the occurrence of long-duration, low-intensity rain can be important in preconditioning a slope for failure under later intense rain by increasing the antecedent moisture content. Certainly, in the case of the Cyclone Cook event, the occurrence of Cyclone Debbie a week earlier and the generally wet conditions leading up to Cyclone Cook will have exacerbated the effects.

Bloomberg *et al (2011)* also noted the debris lying on the ground has the potential to reduce the velocity of overland flow and hence to reduce surface and gully erosion, but that significant accumulations can block small streams causing outbursts that can initiate gully erosion. Further, slash in drainage channels forms traps for sediment from harvesting, reducing sediment migration; but again, larger slash can form small-scale log-jams that can sooner or later fail, releasing large quantities of stored debris and sediment downstream. They noted that at a larger scale, collapsing natural log-jams have been implicated in one of New Zealand's worst debris-flow disasters which occurred at Peel Forest in 1975.

In general, Bloomberg *et al (2011)* were of the view that the risk of accentuating sediment movement by retaining slash on the site is significantly lower than that of removing it. They considered that known situations where accentuated sediment movement has been generated by organic debris are at larger scale than is likely to result from harvesting operations, involving substantial jams of logs from mature trees. Like the prior cited reports, however, there was minimal assessment on the impacts of woody debris downstream of forests.

Amishev, et al (2014) summarise a considerable body of work in their review paper for the Ministry of Primary Industries. They noted that "*at present the paucity of good quality quantitative data collected in a methodical and consistent way precludes establishing robust relationships between rainfall characteristics and on-site factors that may alleviate or exacerbate the severity of storm damage sustained to a forest during extreme rainfall events.*" They also noted that historically landings and roads were considered the primary source of landslides in forested areas but that recently improved practices have resulted in most landslides occurring on cut over slopes with no connection to infrastructure. They commented on the balance between risk and benefits of slash. Among their conclusions was the observation that "*Slash traps have been recommended for managing the offsite effects of woody residue mobilisatio*n." And "*Little information is available on the effectiveness of slash traps*." Again, while a useful summary, the report is focused more on landslides and debris flows and less on the downstream impacts of those events.

Basher, Moores and McLean (2016) citing (Douglas et al. 2011) noted that little work had been done on the source areas for slash that causes downstream problems. Baillie (1999) estimated that 48% of the woody debris mobilised during events was sourced from landslides and 38% from in-stream log jams and debris dams, with the remainder from landing failures and road collapses. Marden and Rowan (2015) reviewed data for an extreme storm event in the Coromandel in 1995. The study noted that one half a million tonnes of sediment were generated mainly by debris avalanches, largely within indigenous forest with 21% generated within standing exotic forest. The study also showed that sediment yields were greater from areas of exotic forest clear-felled three years before the storm event. Interestingly, they noted that sediment yield was greater from the three year old clear felled areas than cut-over cleared just before the storm. Overall they noted that the erosion response was primarily controlled by rainfall variation and slope, and this over-rode the influence of vegetation cover.

Equally, this has not just been a New Zealand issue. Robben (1998) analysed the impact of a series of mass movement events within several sites in Oregon and noted that for the studies cited, the average erosion rate increases for harvest unit and roaded areas are 1.9 times and 186 times background levels, respectively. For other international studies (Swanston *et al* 1985), slash migration was not seen as a particular issue with the "*rate of water movement into and through unstable landforms is critical in determining groundwater conditions and can greatly influenced by the extent and continuity of soil macro-pores*" seen as a primary driver of slope mobilisation.

For the majority of studies, it is clear that the analyses described cannot be directly applied to the Cyclone Cook event detailed here. What is clear is that until now the basic, observational groundwork has not been done to elucidate the character of events such as Cyclone Cook. Our primary findings, namely that slash events could occur in relatively small storm events without slash migration being driven by debris flows is largely/completely absent from the scientific literature. This is not to say that debris flows did not occur, just that of the two significant debris flows that did occur, only one caused a slash event, but slash mobilisation occurred widely in the absence of debris flows. This means that the drivers of slash mobilisation are more complex and driven by both spatial and temporal factors not previously considered in prior work.

5.2 Key Findings

5.2.1 Storm Size

Ex-tropical Cyclone Cook was a relatively small storm with an average recurrence interval of between 1 and 8 years depending on rain gauge location. The duration of peak rainfall intensities was a key driver during the event with rainfall of 80mm+ over a 3 hour duration causing woody debris to mobilise. The area of maximum rainfall was in the headwaters of the Uawa and Waiapu Catchments. A couple of isolated gauges away from these areas also recorded high rainfall but over a longer duration and thus do not appear to have triggered a significant slash mobilisation event. The impacts of Cyclone Cook were exacerbated by the antecedent rainfall conditions with Cyclone Debbie occurring just over a week earlier. An ARI based on the combined storm events has not been calculated.

5.2.2 Location of woody debris events

Woody material was mobilised widely from the Mata to the Hangaroa Rivers but no mobilisation of debris was reported or observed in the Wharerata Range or north of the Mata. The only two events reported in the media were in the headwaters of the Uawa catchment; the flooding in the Mangatokaru which resulted in a family evacuating, and the build up of slash at Wigan Bridge in the Mangaheia. Smaller but still significant events occurred in the Whakoau River and in the lower Waimata River. The other events (Whatatutu, Hangaroa) were minor.

5.2.3 Role of Debris Flows

Only two landsliding events of significance occurred; the Doonholm Slip in the Upper Mangaheia, and the debris flow at “Waterfall Creek” in the Mangatokerau. Smaller debris flows and landslides occurred in a number of locations such as at Duncan Road, at the head of Tauwhareparae Road, between Mangateao and Mangatoitoi streams, Takamapohia stream in the Mangatokerau sub-catchment, and some reactivation of an old landslide in Ruatahunga Stream. Of all of these, only the Waterfall Creek debris flow generated significant slash and produced some but not all of the slash that migrated downstream. In the absence of widespread debris flow development, tracing the slash back to the source was a more complex task than would otherwise have been the case. Despite the lack of widespread major debris flows, silt mobilisation was considerable and thus impacted on water quality.

5.2.4 Role of landings and slash stowage

The Waterfall Creek debris flow was generated adjacent to a landing on Spencer Road (Fraser 2017 and see *Figure 48*) and there were several other landings that showed signs of edge collapse (*Figure 123*). Another area where landings were an issue is where they were placed close to river level making them vulnerable to flooding (See *Figures 43 and 110*). Stowage of slash on floodplains is also common and in a number of instances these have resulted in mobilisation from flood waters (see *Figures 29, 39, 40, 42, 115, 119* and refer **Appendix One**).

Figure 123. Typical edge failure on a landing in the Mangatokerau valley.

5.2.5 Role of Forestry Roads and earthworks

It was found that while not regionally extensive or numerous, those relatively small landslides that did occur were frequently associated with forestry roads or tracks. This is exemplified by the *Figures 27 (Duncan Road) and 37* (*Mangaheia*) above but also in *Figure 124* below which shows a number of severe slips associated with an access track cut in steep land in a west facing slope in a side creek of Manganui Stream in the Mangatokerau sub-catchment. Also evident are a number of small riparian failures at river level and emanating from spurs and extensive slash within the tributary and the main Manganui.

Also observed in the Mangatokerau were extensive earthworks associated with new landing development in confined valleys at river level (*Figure 125*). These earthworks are characterised by lack of separation between the batter and the adjacent stream, the lack of buttressing to prevent slope failure, and the absence of silt traps or fences to stop migration of sediment from the earthworks to the waterway.

Figure 124. View of west facing slope in a side tributary of Manganui Stream showing landslides associated with the track as well as extensive slash within the side stream and Manganui Stream itself and its flood plain.

Figure 124. View of earthworks at river level in the Mangatokerau sub catchment.

5.2.6 Types of slash

A key finding of this investigation is that we now have empirical data on the types of material involved in these events. Deconstruction of the slash piles at Wigan, log counts upstream of Wigan and the plot counts on Tolaga Bay Beach established the dominant role of pine in the woody debris mobilised by Cyclone Cook. This finding is important since it is oft-repeated that the material is "largely willow". This is not to say that willow did not contribute since 30% of the debris was willow or poplar at Wigan (*Figure 89)* and 32% on Tolaga Beach (*Figure 106*). The willows above Wigan had been poisoned but not removed. This means that they are vulnerable during flood events.

Of the nearly two thirds of material that was pine, it was found that the largest proportion of all pine were weathered or abraded logs without root balls at one end (60% of all debris or 67% of all pine). Assessment of this suite of logs indicates that these were originally cut logs and a number were observed with waratah marks (*Figure 83*). Equally significant was the finding that a small but notable proportion of the pine logs observed at Wigan were fresh cut logs. These comprised 6% of all debris (Pine plus willow) or 8% of all pine. Windthrow pine was less abundant at 4% of all debris or 6% of all pine. Similarly, cut logs were observed on Tolaga Beach and at Whakaou Stream (*Figure 122*).

The presence of the fresh cut logs is problematic. They occurred not just at Wigan Bridge, but also in the Whakoau (*Figure 122*) and were evident in Waterfall Creek (*Figure 101*). The observations at Willowbank where cut logs were used to corduroy the approaches to a ford, could suggest that this is the source of some of the fresh cut logs at Wigan. On the other hand, the number of fresh cut logs counted at Wigan (25) as well on the banks upstream (29) is significantly greater than those lost out of the ford at Willowbank. Even if it is assumed that additional logs were supplied from the pile stored on the side of the river at Willowbank the number counted at and above Wigan still exceeds that possible from a Willowbank source.

While anecdotal feedback indicates that some of the logs were sourced from a landing where a load was stacked ready to ship out, no reports of such a load being lost were provided to Council. Equally, the occurrence of similarly cut logs in the Managatokerau and at Whakoau indicates a broader issue with the loss of merchantable logs during Cyclone Cook.

Notably, indigenous vegetation was almost entirely absent at every site, including Waterfall Creek. Fraser (2017) noted, however, "*The mass of soil (landslide) rapidly migrated downslope and typical of these events the landslide has stripped/accumulated logging debris from the cutover and native vegetation from the gully in its path.*" The traverse and log count in Waterfall Creek did not, however, find any indigenous vegetation caught up in the creek floor or perched at levee height. Likewise, no indigenous vegetation was observed at Wigan and only one piece of indigenous was noted at Tolaga Beach.

5.2.7 Slash in gullies and floodplains within forests

Gullies and flood plains with accumulations of pine slash were ubiquitous in all forests (*Figures 27, 29, 38, 40, 42, 43, 50, 52, 65, 79, 91, 92, 116, 118, and 124* and see **Appendix One**). Such slash accumulations were particularly evident in Tapuae Stream (Figures 42 and 43), the Mangatokerau sub catchment (*Figures 91, 92, and 124*), and the Whakoau (*Figures 116 and 118*).

5.2.8 Pine slash in catchments

A key finding of this study is the degree to which woody debris becomes distributed within the catchments beyond the forest. Such slash is obvious where it has been pulled from rivers at locations such as Wigan but concentrations of woody debris is present elsewhere but is less visible.

Traverses of the Mangaheia River, in particular, demonstrated that considerable woody debris; largely abraded weathered pine logs, remained in the river system at flood height level. Such material was especially evident downstream of the Mangateao and Mangatoitoi Streams, between Willowbank and Wigan Bridge, below Wigan Bridge and below the Paroa River bridge. This material will mobilise in any future large flood. By implication, a slash event may occur without any debris flows occurring within a forest, because a flood may mobilise slash within a catchment in an instance where the storm is most intense outside the forest boundary.

A considerable volume of the woody debris observed below Wigan during the over flight (see cover photo) was caught up within the river rather than at flood height. This material is considered to be material released from the bridge during slash removal operations immediately following Cyclone Cook. This material was flushed out of the river during a small flood that followed the over flight and ultimately ended up on Tolaga Beach.

5.2.9 Slash catchers

A key observation from this study is that the slash catchers in the area of highest intensity rainfall during Cyclone Cook either failed (Whakoau, Te Kokokakahi Stream), were damaged and/or overtopped (Managateao, Mangatoitoi) or were bypassed (Mangatoitoi). The replacement slash catcher at Whakoau is already accumulating significant woody debris while a slash catcher in the Mangatoitoi is holding some slash despite there being no major floods since Cyclone Cook. This indicates that the clearing of slash catchers needs to be a regular maintenance activity within catchments.

The bypass and over-topping of catchers raises questions about the effectiveness of slash catchers as a tool for mitigating against the migration of slash beyond forest boundaries. Further, the placement and scale of catchers such as the one at Whakoau means that they are unlikely to be effective during a small event such as Cyclone Cook and definitely not larger events. The Whakoau Slash catcher needs to be rigorously assessed to determine whether or not it will be effective or if additional slash capture tools need to be adopted. It is noted that Amishev *et al*

(2014) observed that slash traps can be used if they do not dam the river, but in Tairawhiti that is largely how they have been deployed.

5.2.10 Standing Vegetation as slash catchers

Both the over flight and field investigations showed that standing vegetation on flood plains and riparian margins can be effective in catching slash in some circumstances. This was observed in Taraewarerewa Stream in the Waimanu Forest (*Figure 24*), above Wigan Bridge (*Figure 84*), and at Te Kokokakahi stream in the Mangatokerau (*Figure 94*) as well as further downstream in the Mangatokerau. The long term effectiveness of this needs to be assessed as it's possible that larger events will mobilise these slash piles and damage the vegetation within the riparian margins.

5.2.11 Use of Corduroy logs in Fords

The ford at Willowbank has been discussed in section 4.2.1.4 and immediately above. The use of corduroy logs in the approaches to fords in catchments vulnerable to flood events is not ideal and a more careful assessment of the most suitable means of installing a river crossing.

5.2.12 Missing Slash

While slash was extensively observed in the Uawa Catchment, no slash was reported in the Mata River downstream of the Whakoau River despite enough slash being mobilised to overwhelm the slash catcher. Subsequent investigations showed that at least pine debris reached the bridge over the Mata at Ihungia but no new material was observed on river banks at Ruatoria or at the river mouth. It is likely that much of the material mobilised at Whakoau is held up on river banks between Bremmer and ihungia Bridges,

6.0 Conclusions

The Event

1. Significant cyclonic events such as Cyclone Cook do not uniformly impact on the region. The location of debris flows and slash mobilisation during the weather system is dependent on the cyclone track and complex topographic variations.
2. The impact of Cyclone Cook was exacerbated by Cyclone Debbie which hit the region a week earlier and left soils saturated and led to greater runoff.
3. The available GDC weather monitoring sites do not have sufficient spatial coverage for analysis of extreme weather events. Forestry company weather stations do not necessarily record data at a reproducible level and the resultant analysis of weather data has to be treated with caution.
4. It is speculated and requires testing, that the Raukumara Ranges causes complex localised weather systems to develop which impacts on the spatial distribution of slash events. Further research would help focus attention on the most vulnerable areas.

The Impacts

5. Forestry slash effects occur during extreme storm events. The resultant debris flows and landsliding can cause or contribute to forestry slash events but as Cyclone Cook has shown, slash mobilisation and silt deposition can occur without debris flows or landslides significantly contributing to the event.

6. Slash in our rivers and reaching our beaches as well as the transfer of soil and silt to the river system during such events has amenity impacts as well as on aquatic systems and water quality.

The Assessment

7. The predominance of pine-based slash was established at multiple sites (70% at Wigan Bridge, 68% at Tolaga Beach) with this comprising mainly abraded weathered logs lost from stored slash piles or elsewhere within the forest boundaries.

8. A key finding of this investigation is the presence of a suite of logs within vunerable catchments that have been resident within the flood plain for a considerable period of time as a result of previous storm-induced slash mobilisation events. It is also clear that at least some of these long resident logs were originally cut merchantable logs and thus had an economic cost to the forestry companies.

9. This suite of logs is prone to remobilisation during high flow events but this makes an analysis of the original slash source difficult. We could identify that much material was mobilised within the catchment but it was only possible to trace slash back to a specific debris flow in Waterfall Creek.

10. Post-Cyclone Cook, a new population of forestry debris has became resident within the flood plains of several catchments. In future events this will be enough to cause risk for built structures necessary for community resilience.

11. The predominance of cut logs in Waterfall Creek (Mangatokerau) and the presence of fresh cut logs at Wigan Bridge and Whakoau indicates that merchantable logs are being caught up in these slash events. This indicates that the Cyclone Cook event represented a direct economic loss to forestry companies. Windthrow pine was present but minor.

12. In the Mangaheia Catchment, woody debris could be traced back to Willowbank Forest, and to the Managatoitoi and Mangateao tributaries, but Doonholm Landslide further upstream from the Managteao did not contribute woody debris.

13. The debris flow above Waterfall Creek in the Mangatokerau was the only significant landslide event that resulted in forestry slash being deposited on the flood plain.

14. A inspection of the overall Mangatokerau Catchment revealed that there were multiple sources of slash upstream of Waterfall Creek, including upstream of Staircase Road and from Te Kokokakahi Stream (where a slash catcher was destroyed by the event).

Forestry operations not aligned with best practice

15. Additionally, both the post-event helicopter flight and on ground inspections indicated that forestry operations had resulted in slash being retained in locations vulnerable to mobilisation by high stream flows. Slash piles was routinely stored on flood plains and slash was ubiquitous in gullies and would be mobilised be even relatively small landslide events. Slash was observed scattered throughout the river systems within forest areas.

16. Earthworks were observed adjacent to streams without suitable safeguards to stop sediment generation reaching the stream while a significant number of both landing failures and poorly designed road cuts were observed. The overall engineering standards applying to forestry infrastructure need to be assessed, and the minimum acceptable standard needs to be higher than current practice.

17. There is a reliance on mitigation measures such as slash catchers but the catchers can be ineffective with at least two instances (Whakoau and Mangatokerau) of slash catchers failing. In other instances (Mangatoitoi and Everetts road) slash catchers were overtopped or bypassed.

Willow management

18. The identification of 30% willows/poplars as a contributor to the Wigan Bridge event indicates that sources other than plantation forests contributed to the event.

19. The management tools for dealing with end-of-life willows within riparian margins needs to be reconsidered. Poisoning may kill the willows but leaves them vulnerable to failure during flood events. Such willows need to be cut down and removed.

20. Likewise, the practice of cutting logs into smaller lengths so that they can pass infrastructure such as at Wigan Bridge appears short sighted as it merely transfers the problem to the coastal zone. Further, releasing slash caught up against bridges rather than pulling it clear of the flood zone merely transfers the problem downstream.

Response and Consequence

21. A number of regional councils have adopted a set of environmental guidelines setting those minimum standards and which provide a measure against which individual operations can be assessed. Gisborne District Council does not have an equivalent guideline but one is needed.

22. Slash events impact upon the whole community and the costs are borne by ratepayers. Amenity values of our beaches and rivers is adversely

impacted. Additionally, the sediment introduced from harvest and post-harvest silt mobilisation causes as yet unquantifiable biodiversity and water quality impacts.

23. Our response to such events should not just the ratepayers of Tairawhiti but involve council, iwi, forest owners and managers, and community stakeholders. The forestry industry is vital to the economic growth of Tairawhiti but long term sustainability requires better management of the impacts.

7.0 Recommendations

Council

1. That in the short term, Council adopt or adapt one of environmental guidelines used by other Councils and work with other councils to develop a national framework that takes into account regional issues as well as the new National Environmental Standard (NES) for forestry.

2 That comprehensive Assessments of Environmental Effects are required for all forestry harvest consents, taking into account the existing environmental values and the measures to be adopted to mitigate those effects.

3 That where practicable, existing harvest consents are reviewed to ensure that the procedures within those consents are fit for the purpose of mitigating against the environmental impacts of the harvest operation and that this is measured against the adopted environmental guidelines.

4. That consents where existing or proposed landings are within flood plains are reviewed to ensure that existing landings are protected from flood impacts and alternative sites are identified where practicable for proposed landing sites.

5. That the effectiveness of current monitoring is reviewed and that cost-recovered compliance monitoring is undertaken on a business as usual basis.

Implementation of best practice within forests

4 That forestry roadways, haulroads and tracks are designed to a standard that minimises risk of failure, with sidecasting avoided as much as practicable and where used, are protected using engineered stabilisation methods.

5 That roadway, haulroad and track watercourses are designed to mitigate against migration of sediment to waterways through the use of silt traps, settling ponds in receiving environments, bunding and silt fencing.

6 That ridge top or spur landings are placed is such a way as to eliminate risk of landing edge failure and that suitable areas are established for stowage of slash in areas where the risk of mobilising slash into gullies and flood plains is minimised. It is anticipated that this is being developed for future consents.

8 That slash catchers are subject to rigorous engineering design and hydrological modeling to ensure that they are fit for purpose, and that existing slash catchers are regularly inspected and cleaned.

9 That incident reporting of any slash event resulting in the migration of slash into waterways is made mandatory.

10 That the current practice of stowing slash on flood plains is discontinued, and existing areas of slash stowage on flood plains are assessed by forestry companies and measures put in place to ensure that the slash is either removed or protected from mobilisation.

11 That forestry companies clear slash from watercourses in areas where slash within permanent watercourses have been identified.

12. That Gisborne District Council and the Environmental Focus Group work more closely to ensure that environmental guidelines, and procedures are fit for purpose.

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