Forestry Harvest Residues on slopes in Makiri Forest and in the Upper Waipaoa Catchment after the Storm of 11th-12th June 2018

M.P Cave
Principal Scientist
Gisborne District Council

Background

Over the 3rd and 4th of June 2018, a major storm event occurred in the East Coast Tairawhiti District causing significant flooding and damage within the region (Queens Birthday 1 event). While moderate rainfall was widespread across the district, a short duration more intense rain cell occurred in a narrow band in the centre of the region from Pakarae in the south to the Mangaheia River in the north.

This resulted in flooding in the Pakarae and Uawa catchments, as well as the mobilisation of a large volume of sediment and woody debris from plantation forests. The event necessitated the dramatic rescue of a family from the Mangatokerau River and others had to self evacuate in the Mangaheia River. The event also re-mobilised woody debris resident on the flood plains of the Uawa Catchment following Cyclone Cook in 2017.

One week later over the 11th and 12th of June 2018, a second major storm occurred but this event exhibited significantly different characteristics (Queens Birthday 2 Event). While peak rainfall intensities were lower than the Queens Birthday 1 storm, the duration of intense rainfall was longer and the distribution more widespread. Both of these weather events are described in more detail in Cave 2018a and 2018b.

The economic, social and environmental impacts of both storms have been significant and recovery efforts continued for several months while some infrastructural damage remains un-repaired. Slash associated with the Queens Birthday 1 event resulted in around 47,000 m^3 of woody debris being deposited on the beach at Tolaga Bay and an initial rapid assessment suggested that 500,000 m^3 of debris was resident within the catchment in locations vulnerable to remobilisation in a storm event. The more widely felt Queens Birthday 2 event again remobilised slash from the previous week's storm but also resulted in significant slash mobilising in the head of the Waimata and Upper Waiapoa Catchments and in the Mangapoike catchment.

The slash on the Tolaga and other beaches have been front of mind for many people and have been documented in a separate report (Estimates of logs on Uawa Beaches, Cave 2018c). It is, however, important to note that the material that reached the beach was just a small portion of the total harvest residues mobilised for the plantation forests. Accordingly, a second study was undertaken to establish the volume of material mobilised by both the Queens Birthday Storm and the storm that followed one week later (**Figure One**).

Three separate reports cover the Uawa Catchment;

- Te Marunga Forest which discharges into the Mangatokerau,
- Paroa Forest which discharges into Tupae Stream, and

- Uawa Forest which discharges into the Mangaheia via the Mangatoitoi and Mangateao streams.

One report covers the Mangapoike Catchment and addresses slash from the Waituna Forest. Two reports cover the forests at the head of the Waimata Catchment. One of these covers the Wakaroa Forest which discharges into the Upper Waimata while the other covers the Makiri Forest which discharges into the Waipaoa.

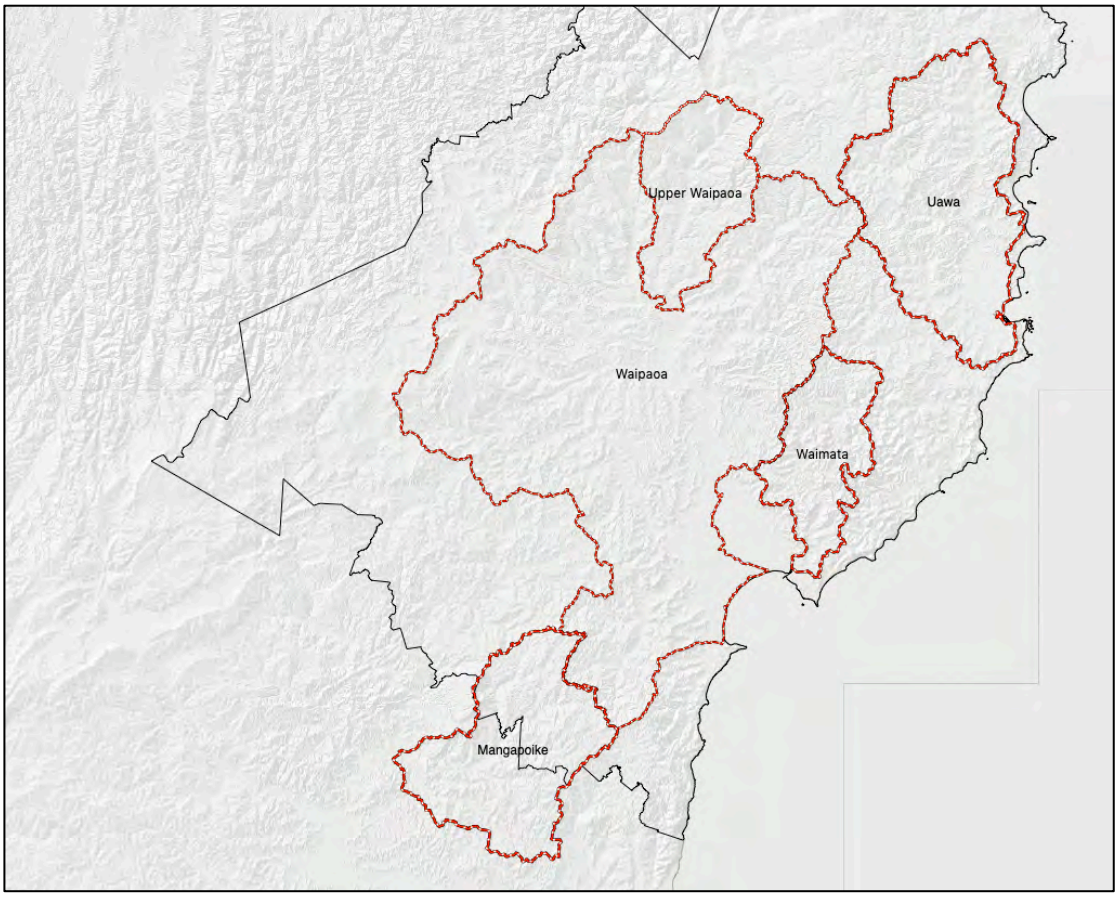

Figure One. *Map of the southern part of the Tairawhiti district showing (from north to south), the Uawa, Waimata and Mangapoike Catchments.*

The primary focus of this study is on the Makiri Forest at the head of the Waipaoa Catchment. Compliance issues with Makiri Forest were first identified on the 17th of June 2018 when 2 photos taken of the headwaters of the Waihora River showed some slipping and slash migration from a forestry road. At the time, the investigation team was focused on the Uawa catchment because of resource constraints. Thus, it was not until the 7th of July 2018 when a helicopter returning from an inspection of Westho Forest was able to more closely examine issues in the forest. In particular, this over-flight identified significant issues with landings along a roadway that ran north-west from Duncan Road (**Figure Two**). This shows a series of landings

(Landings 8 through to 11) which showed signs of significant recent slope failures, birds-nests and slash migration. The forest was then inspected on the ground by warranted officers on the 10th of July 2018 which confirmed the assessment formed after the 7th of July flight.

Figure Two. *View of Makiri West Road (7th July 2018) showing landings 8 through to 11. These landing numbers were assigned by GDC as the forest owner did not provide a map giving alternative names. The photograph shows that there were extensive birds-nests of harvest residues placed on slopes (particularly those slopes on the left) as well as extensive slope failures.*

Methodology

Satellite Imagery analysis

Initial estimates of the volume of material within the forest has been estimated using post-event satellite imagery particularly that of 13th July 2018 and supplemented by 25th August 2018 imagery. Following qualitative assessment of the various datasets, the principal quantitative method has been based on digitising high-resolution post-event satellite imagery. Overall, this methodology may not be as robust as the process in Cave (2018c), where detailed volumetric measurements on the ground as could be undertaken.

Additionally, as the satellite imagery was acquired in the middle of winter, it has areas of shadow and in these areas key features cannot always be as

accurately resolved. In part this could be accommodated by comparing the primary image set (13th July 2018) with the 25th of August image set. In addition, image resolution was affected by several parameters;

1. Effective resolution was highest on flat to nearly flat ground,
2. Areas on the western sides of slopes were in full or partial shadow,
3. Areas of steep east facing slopes had a lower apparent resolution resulting from transit velocity anomalies,
4. Satellite geo-referencing resolution was variable depending on overall image resolution with slash debris in the lower resolution 25th August dataset offset by around 1 m relative to the high resolution 13th July dataset and with an azimuth variation of around 5°.

Irrespective of these constraints it was possible to identify a series of key elements such as;

1. Cut logs,
2. Stumps in ground,
3. Trees cut to waste and abandoned on slope,
4. Trees that were either windthrow or knocked down and not recovered during harvest operations,
5. Short ends cut to waste including slovens, mobilised stumps, and shorts,
6. Stockpiles (birdsnests) in locations vulnerable to landing collapse,
7. High reflectance logs (bright reflective logs or log piles),
8. Low reflectance logs (dark coloured logs) typically on slopes
9. Silt or sediment covered logs or log masses.
10. Chaotic masses of either logs or finer diameter material caught up on plains or riparian margins.

The analysis also included tracking the slash from Makiri Forest down two un-named tributaries to the Waihora River (a significant tributary to the Waipaoa) to as far as the junction of Kanakania and Bruce Roads north of Te Karaka. It is probable that slash travelled further, however, that was the extent of the high-resolution satellite imagery available to GDC.

Supporting field assessments

Photographs from helicopter flights and site visits were used to validate the analysis. The images taken during the site visits were acquired using 2 Canon 7D Mark II cameras which have a built in GPS (global positioning system) which allows for location (latitude & longitude), altitude and azimuth (orientation of the camera) to be determined. Other photographs were taken with a Nikon D850 and iPhones all of which recorded geo-referenced data.

These photographs were then stored in specialised Digital Asset Management software (Aperture) with key attributes recorded (photographer, file name, day and date, and location). Files are stored as camera Raw files with associated metadata which contains the locational information along with other key attributes such as camera type, lens type, aperture, shutter speed and focal length.

The Aperture software allows for the images to be viewed either as individual photographs or as a series of thumbnails. These thumbnails could then be directly printed out as contact sheets or alternatively exported as pdf files. The metadata could also be exported as a text file which was then converted to a CSV (comma separated value) file in Excel and then loaded into a GIS allowing the locations where each image was taken to be shown on a map (**Figure Three**).

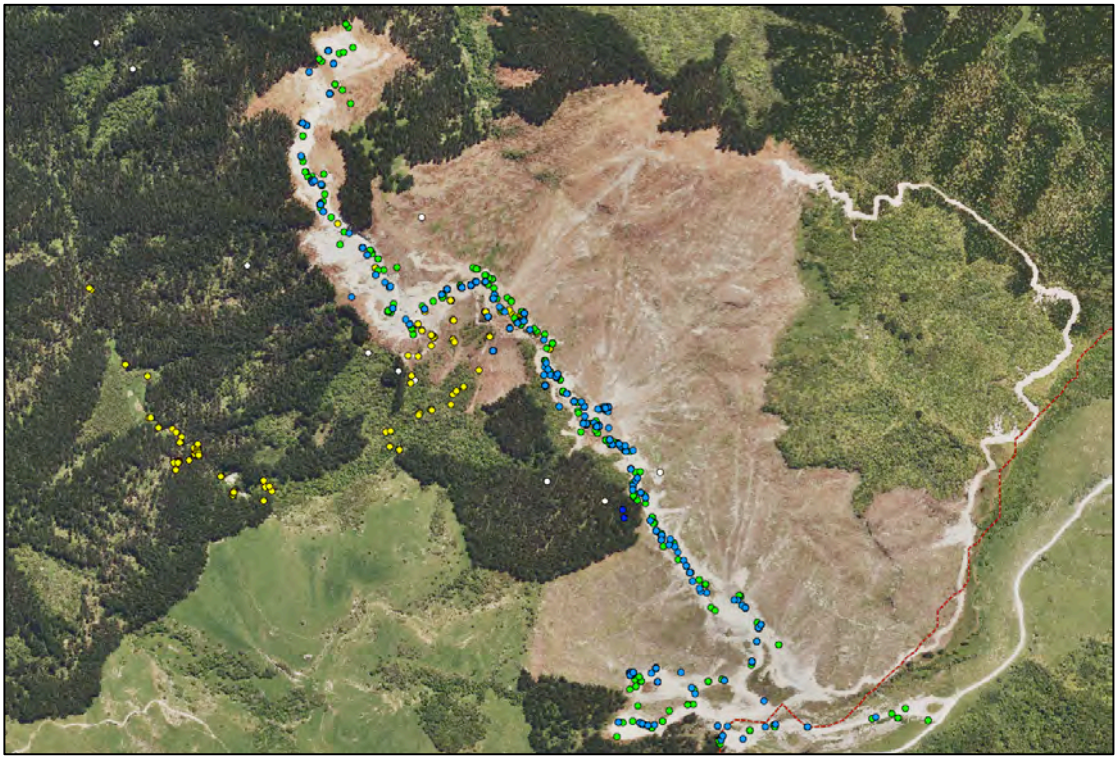

Figure Three. *Aerial view of Makiri Forest with the geo-referenced locations of individual photographs shown as circles. The different colours denotes different photographers (the white and dark blue circles are from a helicopter while the yellow, green and light blue are ground based images). A total of 713 ground-based images were used in-forest as well as 13 helicopter-based images.*

Quantitative analysis

The quantitative analysis comprises two components; calculation of the area of forest that had been harvested immediately prior to the second Queens Birthday storm event (11-13th June 2018), and the analysis of the area occupied by slash within that forest. While an aerial extent analysis of the slash identified in the catchment can and has been calculated, it is also the case that much of the Waihora River is in shadow and hence the downstream

volumes are a bare minimum and need to be considered as only indicative of the risk posed by slash resident within the catchment.

In addition, it needs to be stressed that because of the remote sensing methodology employed, only the area occupied by slash and not volumes or mass were calculated. This is a key point since the volume and mass of slash that were generated from the forest will significantly exceed the calculated area reported in this analysis.

Harvesting in Makiri Forest was initiated in 2017 and by the 17th of August 2017 58.25 Ha of forest had been harvested. Harvesting activity ceased in early 2018 with a total of 87.1 Ha of harvest completed. Active harvesting and maintenance of the forest ceased in early 2018 due to a dispute between the forest owner and contractors (**Figure Four**).

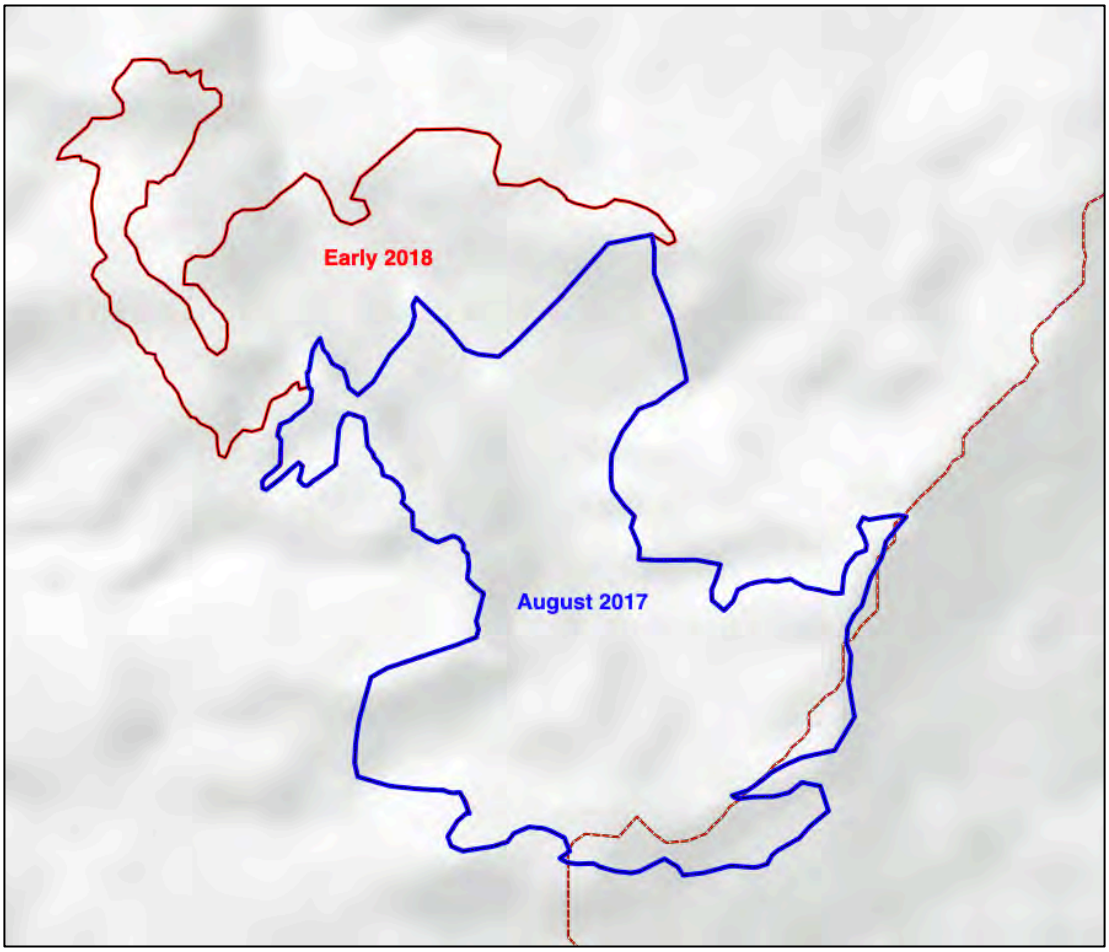

Figure Four. *Makiri Forest showing the areas harvested by August 2017 (58.25 Ha) and at the end of harvest in early 2018 (87.1 Ha).*

A total of 2544 discrete shapes associated with slash have been counted both within and beyond the forest. These comprise both individual logs and substantial areas where it is not possible to identify individual logs based on the high density of debris. On an area basis around 93,000 m^2 or 9.3 Ha of the forest is covered with slash (9.3% of the harvest area) (see **Figure Five**).

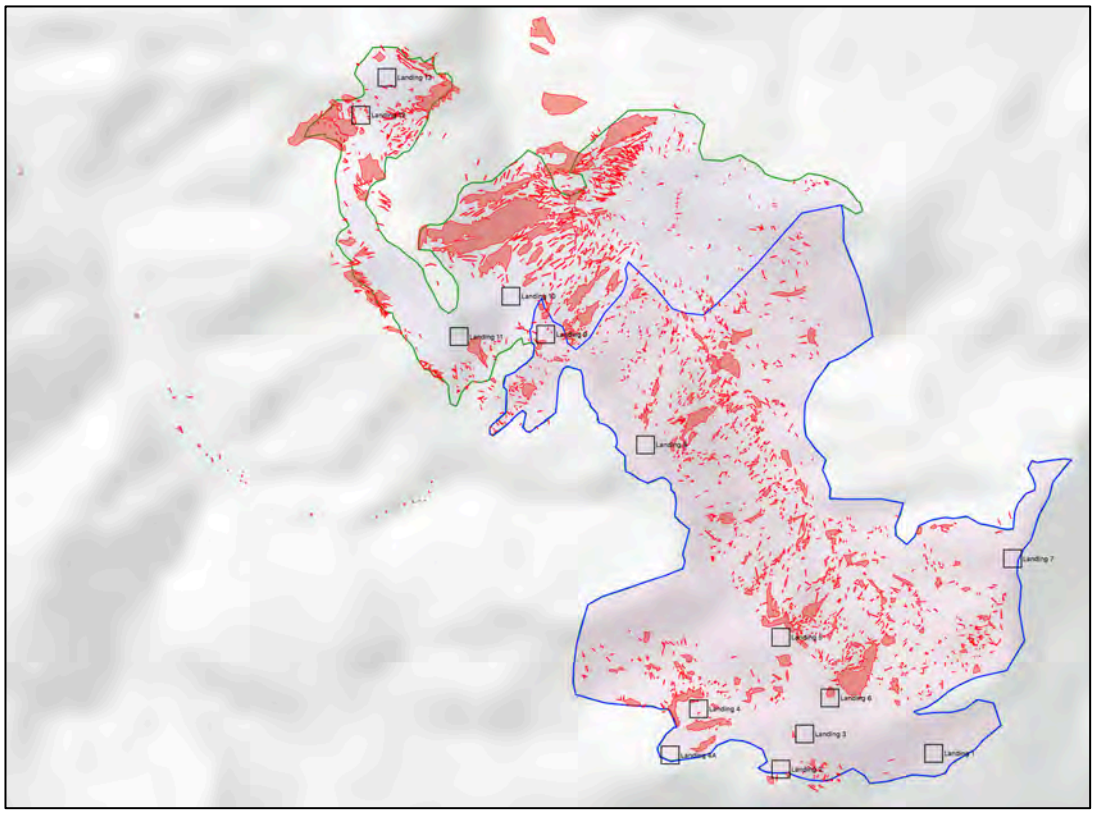

***Figure Five**. View of Makiri forest showing the mapped distribution of slash within the forest (Red outlined areas) and immediately downstream in an unnamed true left tributary of the Waihora River.*

In addition, an area of around 3,812 m^2 (0.3812 Ha) of slash is located between the forest and the end of the high resolution satellite imagery near Kanakania (**Figure Six**). The Waihora River has not been traversed on foot due to the health and safety risk this would pose and as noted is partially in shadow. Thus the area of slash calculated is indicative only and the likely area of slash within the catchment is likely to be of an order of magnitude greater.

Irrespective, analysis of the satellite imagery and an on-ground assessment from Kanakania and Bruce Roads show that slash migrated at least 15 kilometres down the Waihora River and may well have migrated further.

Locational Analysis

While some forestry companies provided information on the naming of forestry roads and skid (landing) sites, this was not the case for Makiri Forest. Accordingly, the forestry roadways (Makiri West and Makiri North) and skid sites (1 to 13) were named by the Operation Queens Birthday investigation team (**Figure Seven**). Photographs discussed below are described in relation to these skid numbers and roadways.

***Figure Six**. View of Makiri Forest (bottom right) and the slash debris in the Waihora River downstream of the forest. The larger red circles are the verification sites which were visited on the ground.*

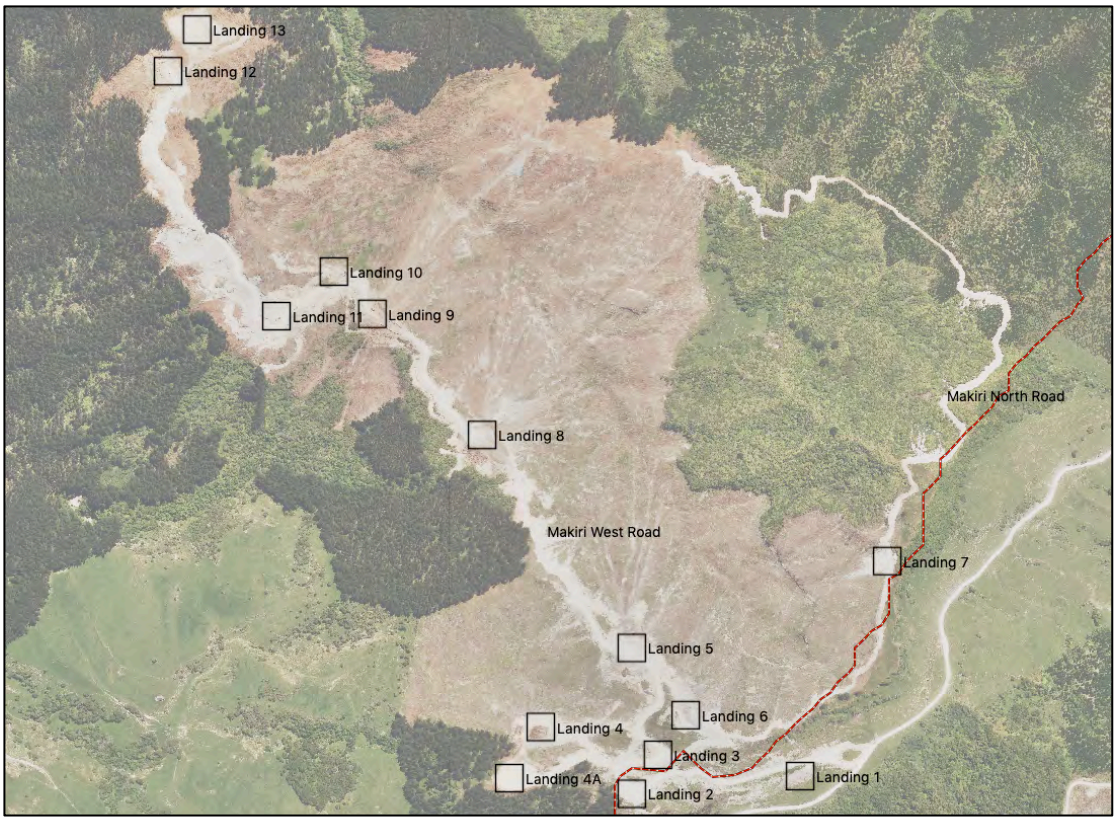

***Figure Seven.** Road names and skid numbers for Makiri Forest (GDC names).*

Landing One

Landing 1 based on the July 13th 2018 satellite imagery is shown in **Figure Eight** below. This shows that the harvest practice was to stow harvest waste on the edge of the landing. In this instance, however, despite the significant volume of harvest residues left on the edge the risk of slash migration due to slope failure is minimal (**Figure Nine**).

Figure Eight. *July 13th 2018 satellite image of Landing One, Makiri Forest.*

Figure Nine. *Significant birdnest on the edge of Landing 1. Because of its location there is minimal risk from this site.*

A characteristic observed in Makiri Forest was the poor house-keeping on the site with rubbish that should have been removed scattered on landings and areas adjacent (**Figure Ten**).

Figure Ten. *Plastic containers abandoned on site adjacent to Landing 1. Similar waste was observed on a number of landings or the edges of roadways.*

Landings Two and Three

Landings 2 and 3 appear to be small skid sites used as short-term sites for harvesting from the planned roadway and as such the amount of material involved was small (**Figure Eleven**). As such, the overall volumes of slash on the slopes was quite low and the size of opened forest also quite low with slash from landing 2 unable to migrate to farmland below because of remaining un-harvested trees.

At Landing 3, a gully had been closed off by a road construction with a large culvert installed but this culvert had been largely blocked by logging slash (**Figure Twelve**) and there is further slash stowed in the gully that could exacerbate drainage long term.

Figure Eleven. *View of landings 2 and 3 showing photo locations and the location of slash on slopes below the site.*

Figure Twelve. *View of gully below Landing 3 slash clogging the culvert.*

Landing Four

Landing 4 is located immediately north west of Landing 2. This landing was used for full harvest on the adjacent slopes and is characterised by a large slash birdsnest on its northern edge and extensive slash on the slopes below the landing as well as in the watercourse below the site (**Figure Thirteen**).

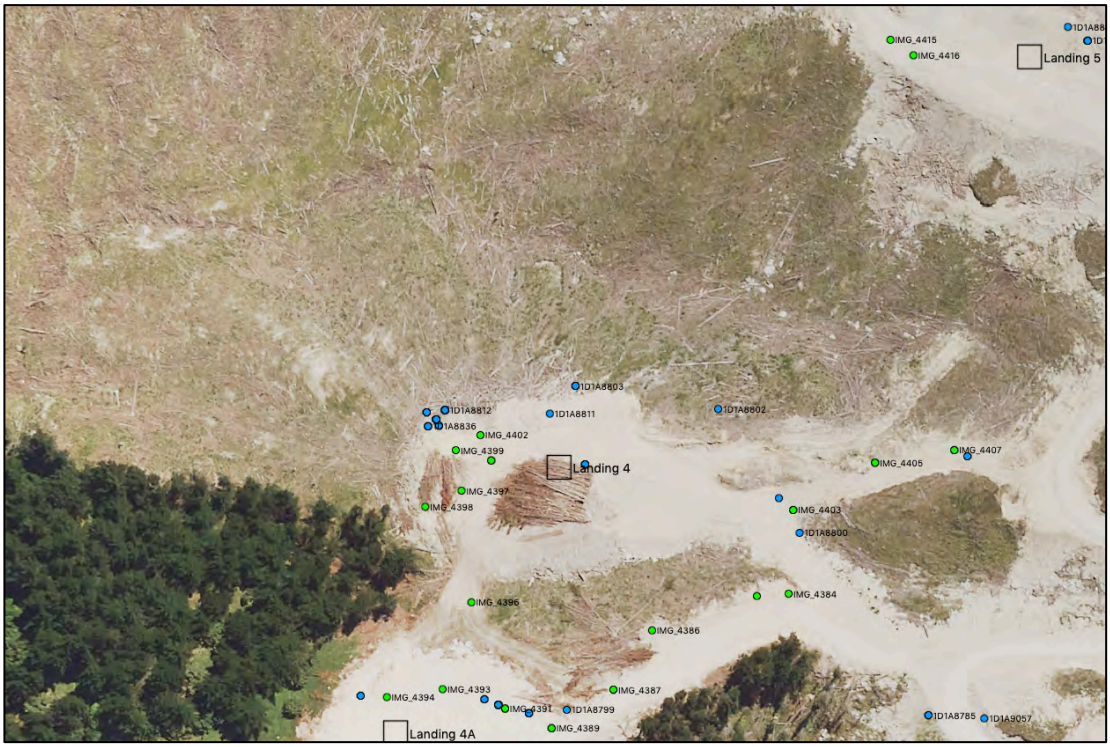

***Figure Thirteen**. January 2018 aerial photograph of Landing 4, Makiri Forest showing the distribution of slash on the edge of the landing as well as on adjacent slopes. Landing 5 is shown at the top right corner (see **Figure Fourteen**) below. Also shown are the geo-referenced locations and image numbers for the photographs taken on the landing.*

The volumes of slash at Landing 4 is evident in **Figure Fourteen** below which shows the extent of slash on the western end of the skid site. While some of this is relatively narrow diameter harvest waste it also includes a significant number of cut logs as is shown in **Figure Fifteen**. Forest harvest waste is also present on the northern edge of landing 4 where it forms a significant birds-nest (**Figure Sixteen**). Also evident in **Figure Sixteen** are the volumes of harvest waste on the adjacent slopes and below Landing 5 (top right of **Figure Sixteen)**.

Landing Five

Landing 5 is shown in **Figure Seventeen** below. This shows that the harvest operators have attempted to use a bench to arrest the migration of harvest residues downslope from the landing. As is also evident from both **Figure Seventeen** and **Sixteen**, however, is that any bench if present was ineffective as the harvest residues beyond the bench have migrated downslope despite **Figure Sixteen** showing that the bench extended to as far as that harvest

residue material. Also evident in **Figure Seventeen** are the logs at the base of the gully at bottom left. While such material is often referred to as windthrow, this is clearly not the case as cut ends and de-limbing has clearly occurred.

***Figure Fourteen**. Harvest waste stowed as a birdsnest on the western edge of Landing 4. While a significant amount of the material in this photograph is relatively small diameter slash it also includes cut logs as is shown in **Figure Fifteen** below.*

***Figure Fifteen.** View of the birds nest on the western end of landing 4 showing the cut logs incorporated in the debris.*

Figure Sixteen. *View of large birds nest on northern slope immediately below Landing 4. Also evident is a birds nest at landing 5.*

Figure Seventeen*. View of Landing 5 from main Makiri forest roadway showing slash accumulation on bench as well as slash that has migrated beyond any bench in the background. Trees discarded during the harvest operation are evident in the foreground at bottom left. The Landing 5 birds-nest shown in* ***Figure Sixteen*** *is the same as the background birds-nest in this image. (****Figure Seventeen*** *is a composite of images 1D1A8844 to 1D1A8848).*

Landings Six

An aerial view of the section of forestry roadway between Landing 5 and Landing 6 is shown in **Figure Eighteen**. As this shows, Landing 6 has a large volume of harvest residue material that has been displaced downslope. The

pre-event aerial imagery (January 2018) suggests that there had been a limited post-harvest attempt to recover slash from the top of the slope after harvest but the bulk of the harvest residues remained beyond the reach of whatever machinery was employed. This remained the case in the 13th of July 2018 post-event satellite imagery but a satellite imagery between the end of August and December 2018 suggests that some clean up had been attempted but was largely ineffective as much of the slash was beyond the reach of whatever machinery was used.

The same landing dated 13th July 2018 after the Queens Birthday storms is shown in **Figure Nineteen** below. As this image is based on satellite imagery it looks texturally different from the aerial imagery in **Figure Eighteen** but essentially shows the same story. The birds-nest at the edge of Landing Six is well evident as is the tail of slash distributed down the slope below the landing.

Figure Eighteen. *Aerial view of Landing 6 located south east of Landing 5 in Makiri Forest. Also shown are the geo-referenced locations where photographs were taken (Note that where numerous photographs are taken at one site the GIS does not show all photographic version numbers).*

Figure Nineteen. *13th July 2018 satellite view of Landing 6 located south east of Landing 5 in Makiri Forest. This suggests that no landslide occurred at this particular site during the Queens Birthday or 11-12th June storms but there is a significant amount of slash that has migrated downslope from the landing and entered the watercourse at top right.*

Between Landing Five and Six

The use of corduroy logs to support the roadway between Landing 5 and 6 as shown in **Figure Twenty** below is significant. While this can be an effective short-term measure to provide support for operations, its stability long-term is constrained.

Corduroy support for roadways are prone to settling and water infiltration as the logs start to deteriorate and the logs move under the weight of machinery. In this instance a single log has been driven into the fill below the corduroy to help maintain stability but this has begun to rotate outwards indicating subsidence of the fill on the slope.

Figure Twenty. *Use of corduroy west of Landing 6 (in background). Use of such corduroy is not an effective long term means of supporting the roadway and in this instance a log has been driven into the fill slope below in an attempt to improve support but this has started to rotate downslope. Note the present of slovens mixed up with the corduroy. The loss of harvest residues downslope at Landing 6 is evident in the background.*

Between Landings Five and Eight

Significant slope failures and slash migration to the creek bed north of Makiri West Road is evident between Landings 5 and 8 based on 13th July 2018 satellite imagery (**Figures Twenty One and Twenty Two**). There is no indication of this slash migration or the slope failure in satellite imagery immediately pre-dating the Queens Birthday and 11-12th June storms (17th May 2018). In **Figure Twenty Two**, Two large clusters of harvest residues are evident in the creek at and immediately below the slope failure shown in **Figure Twenty One**.

An inspection of the creek downstream of these landings on the 16th of October 2018 located slash that can be tracked back to this creek north of Makiri West Road. Satellite imagery shows further slash downstream of the furthest point visited during the inspection. **Figure Twenty One** also shows extensive on the slopes both upstream and downstream of where this slope failure connects with the creek.

***Figure Twenty One**. View of the slope north east of Makiri West Road showing extensive slash distributed on the slopes between Landings 5 and 8. Two clusters of slash in the creek bed are evident at the top of the image (13th July 2018 satellite). These two clusters are more evident of **Figure Twenty Two** below.*

***Figure Twenty Two.** Detail of Figure Nineteen above showing the slash on the slope and in two clusters in the creek (13th July 2018). This slash and the clusters is not evident in the immediate pre-event imagery.*

Landing Eight

Landing 8 is located west of Landing 5 on Makiri West Road (see **Figure Seven**) Landing 8 was used to harvest logs from the north side of Makiri West Roadis significant as it has experienced significant failure during the event. This Landing and the extensive photographs taken at and adjacent to the site are shown in **Figure Twenty Three** below.

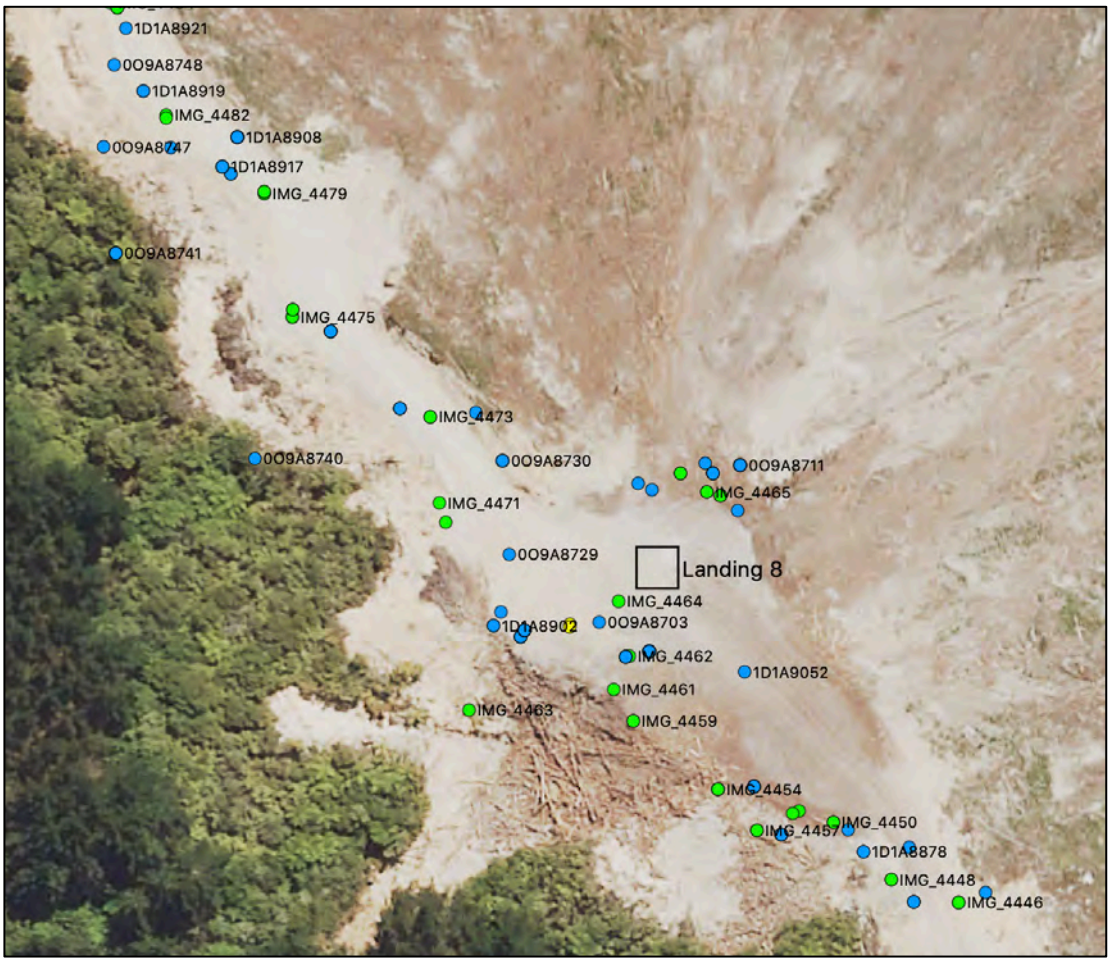

Figure Twenty Three. *January 2018 aerial image of Landing 8 showing the location of the many geo-referenced photographs taken in the vicinity of the Landing and the harvest residues that have collapsed.*

This site was characterised by the presence of a substantial birdsnest on the south western side. This comprised of harvest resides which includes dross (Waratah waste), slovens (short cut ends), and cut logs. Also evident at this site was a substantial tension crack (**Figure Twenty Four**). A wider view of the site is shown in **Figure Twenty Five**. This shows an obvious bench which has clearly failed. Comparison between satellite imagery dated 17th May 2018 (pre-event) and 13th July 2018 (post-event) shows that the failure occurred between the two dates. **Figure Twenty Five** also shows the steepness of the slope at the birdsnest and an apron of slash on the slope below the landing.

Landing 8 was also discussed in a separate report into the landslide activity in the Wakaroa and Miriki Forests (Cave 2019) which found that a considerable amount of slash had been discharged down slope on the south western side of North Makiri Road. That analysis also indicated that at some stage fill material appeared to have been laid on top of the harvest waste to form a wider landing.

***Figure Twenty Four**. View of the birdsnest at Landing 8 showing the dross, slovens, cut logs and obvious tension crack at the right side of the photo.*

***Figure Twenty Five.** View of the south western side of Landing 8 looking west showing a failed bench in the middle ground and the slash apron extending down slope to the south.*

Analysis of the 13th of July 2018 satellite imagery also shows that considerable slash had migrated downslope on the north eastern side of Makiri West Road and has reached the watercourse below and which ultimately feeds into the Waihora River which is a major tributary of the Waipaoa (**Figure Twenty Six**) and this is also evident in **Figure Twenty Seven**.

Figure Twenty Six. *Satellite image of Landing 8 Makiri Forest dated 13th July 2018 (post Queens Birthday storms) showing the landing collapse on the northern eastern side with a significant volume of harvest waste collected on the slope as well as in the top of the tributary of the Waihora river (top right of image).*

Figure Twenty Seven. *View of the north eastern side of Landing 8 Makiri Forest showing the landing collapse with a significant volume of harvest waste displaced down the slope and also showing considerable harvest waste in the water course below.*

Landing Nine

Landing nine is located just under 300m further north-west along Makiri West Road and based on the 17th of August 2017 satellite imagery was under construction at this time. Aerial imagery dated 12th December 2017 shows that the landing was being actively used for harvesting by the end of 2017 (**Figure Twenty Eight**). This aerial imagery also shows that a considerable volume of harvest waste had been discarded onto the slope immediately south-west of the landing with lesser but still significant harvest waste lying on the slopes to the north-east of the landing.

Figure Twenty Eight. *View of Landing 9, Makiri Forest (12th December 2017) during active harvesting showing the birds nest of harvest waste immediately south-west of the landing and a significant volume of harvest waste scattered on the slope to the north-east. Also shown are the locations where photographs were taken on site.*

A closer look at the same image suggests that a bench was constructed to capture the harvest waste (**Figure Twenty Nine**), but this bench was ineffective however, as harvest waste can be seen distributed below the bench. There are also two small landslides that have been generated from the harvest waste below the bench. As was the case with Landing 8, considerable volumes of merchantable timber had been stacked on top of harvest waste at the edge of the landing (see Cave 2019, **Figure Thirty**). This is a risky practice as the loading on the landing edge can result in a slope failure if the loading forces exceed the strength of the materials on the landing edge. This risk is exacerbated if the ground becomes saturated after heavy rain.

The migration of harvest waste down slope to the south-west from Landing 9 is shown in **Figure Thirty** below. This image overlays the position of the harvest waste from the 13th July 2018 on the 12th December 2017 aerial imagery. Also shown is the outline of the slope failure that postdates the December 2017 imagery.

Analysis of the 17th May and 13th July 2018 satellite imagery indicates that the major slip shown in **Figure Thirty** was not present in May 2018 but was present in the July 2018 image. A view of the south-west slope from the edge of Landing 9 is shown in Fi**gure Thirty One** (Composite of images 1D1A8928 to 1D1A8930 dated 10th July 2018).

This image shows that the slope failure has the characteristics of a high-energy debris flow with logs perched high on the slope aligned with flow direction and obvious trim lines. In addition, the amount of harvest waste visible is considerably less than would be expected based on the pre Queens Birthday storms aerial imagery (December 2017) which shows a significant amount of slash in a birds-nest perched on the south-western slope. This indicates that the debris flow has allowed much of the slash to migrate further down the catchment.

Figure Twenty Nine. *Detailed view of Landing 9 dated 12th December 2017 showing the merchantable logs stowed on the edge of the landing, the ineffectiveness of the bench in preventing migration of harvest waste and the presence of small slips below the bench.*

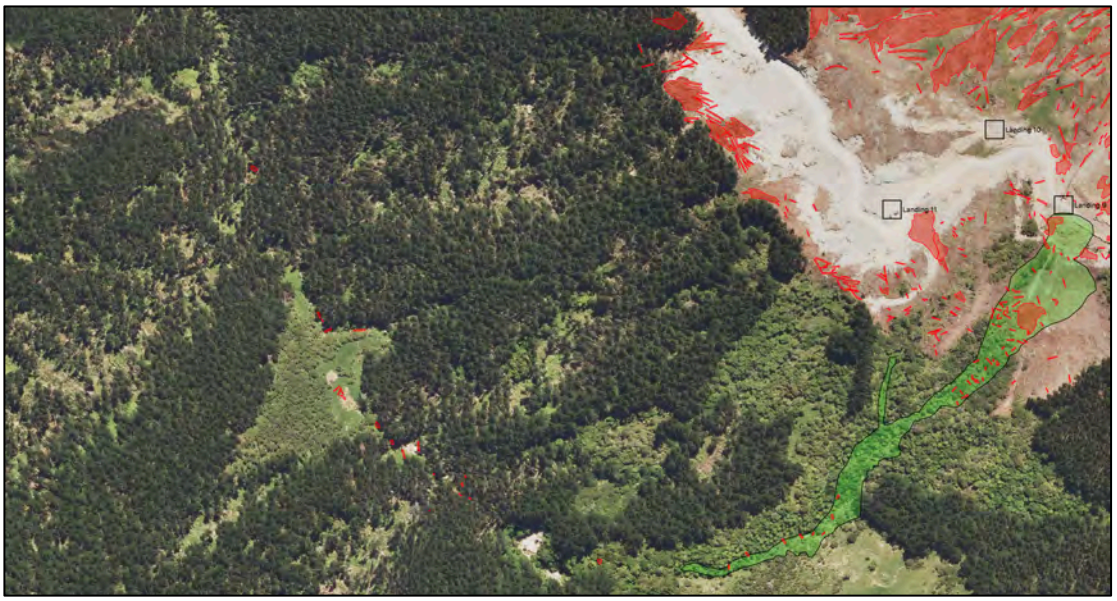

Figure Thirty. *View of the area south-west of Landing 9 showing the position of harvest waste that has migrated into the true left tributary of the Waihora River (red) and the outline of the slope failure from the 13th July 2018 satellite imagery plotted onto the 12th December 2017 aerial imagery.*

Figure Thirty One. *Composite image (photographs 1D1A8928 to 1D1A8930) south-west of Landing 9 showing the path of the debris flow and the pronounced trimlines of the debris flow edge. Only a remnant of the birds-nest identifiable in the 12th December 2017 aerial image remains.*

Harvest waste was also shed onto the slope north east of Landing 9 as indicated in the 13th July 2018 satellite imagery (**Figure Thirty Two**). Comparison of the May and July 2018 satellite imagery shows that the obvious slope failure on the north-east side occurred after the 17th of May 2018. The watercourse is in shadow in **Figure Thirty Two** but **Figure Thirty Three** shows the presence of harvest waste in the watercourse.

Figure Thirty Two. *View of the north-east side of Landing 9 (13th July 2018 satellite) showing the remnant birds-nest (bottom left) and the mobilization of harvest waste down slope.*

Figure Thirty Three. *View of the north-east side of landing 9 (composite image 1D1A8933 to 1D1A8938) showing the remnant birds-nest. On the left of the large cut log on the far left a tension crack has developed. The base of the debris flow of harvest waste is evident on bottom right while the presence of harvest waste in the watercourse is also obvious.*

Landing Ten

Landing 10 is located on a spur track around 100 metres north-west of landing 9 on Makiri West Road. The landing was under construction on the 17th of August 2017 and by the 12th of December 2017 trees on the north-east of the landing had been felled but not harvested (**Figure Thirty Four**). This remains the situation at the present day. It is known that the forestry contractors had withdrawn from the forest at some stage in early 2018 and it is presumed that these trees were abandoned rather than deliberately felled to waste. Most of this material appears to have largely remained on the slope although one narrow failure from the north-western edge of the landing has resulted in some trees sliding downslope.

It is not clear from the immediate post Queens Birthday storm satellite image (13th July 2018) whether or not some of the felled trees reached the watercourse. Lower resolution satellite imagery of 25th August 2018 indicates, however, that there are felled trees adjacent to the creek while a oblique aerial photograph (0O9A8487) clearly shows the creek clogged with felled trees (**Figure Thirty Five**).

Figure Thirty Four. *View of the northern side of Landing 10 showing the abandoned felled trees and the narrow debris-flow which has mobilised some trees on the slope 13th July 2018). Because of shadow this satellite image does not show whether or not the felled trees reached the watercourse.*

Figure Thirty Five. *View of the northern side of Landing 10 showing the abandoned felled trees on the slope as well as in the watercourse. (Photograph 0O9A8487 7th July 2018 oblique aerial image).*

Landing Eleven

Landing 11 is located around 130 metres south-west of Landing 10. It appears to have been primarily used for harvesting a relatively small area to the south and west of the landing, and partly for road-lining towards Landings 12 and 13. Based on satellite and aerial imagery the harvest took place between the end of August 2017 and the beginning of December 2017. The volumes being harvested at this site was less than for the previously discussing landings, none-the-less, the imagery shows that a large birds-nest of harvest residues was left on the slope immediately below the landing (**Figure Thirty Six**).

Figure Thirty Six. *Satellite image (17th May 2018) of Landing 11 showing the harvest residues immediately below Makiri West Road.*

This landing was inspected on the ground by council officers on the 10th of July 2018 which confirmed the presence of a significant volume harvest residues as well as a debris flow originating at the site (**Figure Thirty Seven**). A closer examination showed that the birds-nest appeared to be sitting on a bed made up of corduroy logs (**Figure Thirty Eight**) but this has been undermined by a debris flow that resulted from a slope failure from the opposite site of the landing (**Figure Thirty Nine**).

Figure Thirty Seven. *View looking west to the harvest residues at Landing 11. Also evident was a bench which does not appear to extend to the base of the birds-nest. Also evident is an expansive area lacking any vegetation cover and logs in the creek bed below the birds-nest.*

Figure Thirty Eight. *View looking west to the harvest residues at Landing 11 showing the slash supported by corduroy logs. Also visible is the trimline for the debris flow from the site. This may have been a retaining wall of logs that has failed.*

Figure Thirty Nine. *View of Landing 11 (with Landing 9 at the bottom of the image and Landing 10 at far right) showing the failure from the top of the slope (top right) crossing the road. The edge of the debris apron for this event does not appear to have extended beyond the birds-nest but may have triggered a slope failure at the edge of the birds-nest.*

Landings Twelve and Thirteen

Landing 12 is located just under 500 metres north-west of Landing 11 and Landing 13 is a further 90 metres north-east of Landing 12. The sites were operation during December 2017. These two Landings are discussed together since the analysis and other information indicates that full harvest had been abandoned once Landing 11 was established. Harvesting was then largely restricted to that necessary to allow the roadway from landing 11 to 13 to be completed.

As a consequence, the forest development after Landing 11 did not result in conditions likely to result in the migration of harvest residues into environmentally risky situations. This did not necessarily mean that in-forest practices improved, indeed that wasn't the case. Rather, because harvest was confined to that necessary to develop the roadways, developments were such that migration of harvest residues to watercourses was less likely. Both landings are shown in **Figure Forty** below.

At both landings trees have been felled and partially left to waste on the slopes below the Landings but a birds-nest at Landing 12 and untrimmed logs on landing 13 suggests that some harvest processing has occurred. Post Queens Birthday storm satellite imagery shows that no harvest residues

Figure Forty. *Aerial view of Landings 12 (Top left) and 13 (right) [7th July 2018] showing a birds-nest on Landing 12 and felled to waste timber on both sites. No indication was found of harvest residues migrating beyond the roadlining corridor.*

Downstream Slash Migration

The Waihora River area below Makiri Forest is rugged and inaccessible until the valley widens out at Bruce Road, Kanakania. As such, the Council relies on landowners or contractors to report the presence of slash on their properties. In the case of Makiri, no downstream reports were received but once the high resolution satellite imagery was available, the harvest waste could be traced downstream. The harvest waste from Landing 9 (see **Figure 30** above) could be traced 1.5km down the true left branch of the Waihora while harvest waste from the north-east side of Makiri West Road could be traced 2.2km down the true right tributary of the Waihora River to its confluence with the main branch (**Figure Forty One**).

Following the identification of slash in the satellite imagery, the Kanakania-Bruce Road area was visited on the 7th of June 2019 and locations recorded on the satellite imagery verified (**Figure Forty Two**). This confirmed that slash had been washed downstream after the second Queens Birthday storm with a local landowner also reporting that at least 100 tonnes of slash had been caught up on river flats within the farm (Brian Milligan pers comm June 2019).

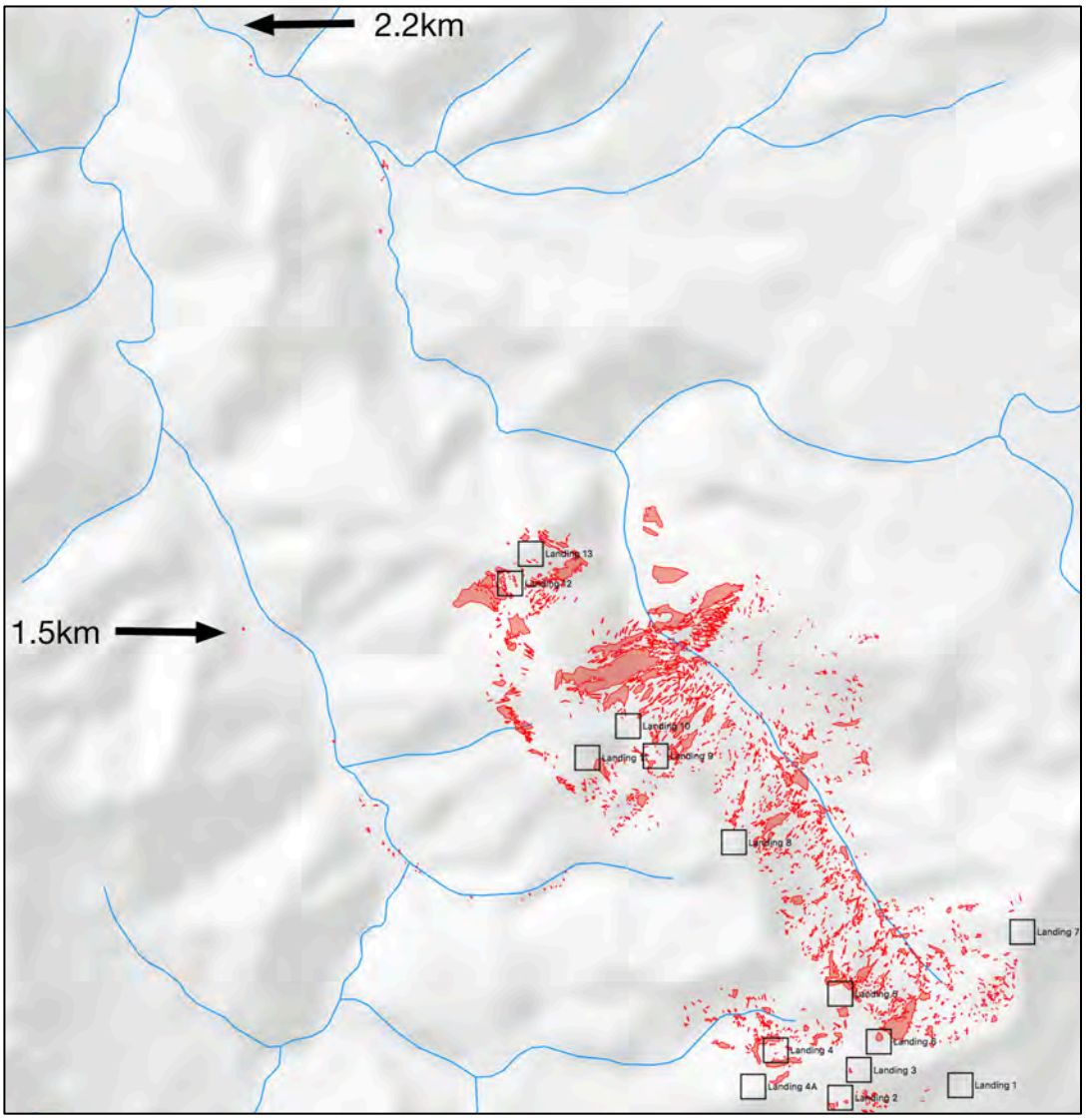

Figure Forty One. *Map showing the distribution of harvest residues immediately downstream of Makiri Forest in the tributaries of the Waihora River.*

Figure Forty Two. *Aerial image of Kanakania Bruce Road area showing slash plotted from the satellite imagery and the on the ground photograph locations.*

A detail of the 13th July 2018 satellite imagery with the location of individual logs is shown in **Figure Forty Three** below, while specific clusters of logs are shown in **Figures Forty Four** and **Forty Five**.

Figure Forty Three. *Harvest residues identified from high resolution satellite imagery (13th July 2018) in the Waihora River downstream from Makiri Forest.*

Figure Forty Four*. Forestry logs that have been pulled from the Waihora river upstream of the Bruce Road Bridge (Image 1D1A6622).*

***Figure Forty Five**. Harvest residues as well as some willow caught up against trees on the banks of the the Waihora river (Image 1D1A6646).*

Conclusions

1. Development of roadways in Makiri Forest started in January 2017 and by the time ex-Cyclone Cook hit on April 12th harvesting had taken place from Landings 1 to 4, and Landing 6, and road lining operations were underway to Landing 5. Therefore ex-Cyclone Cook can be ruled out as a source for the slash in the Waihora River.
2. By the 17th of August 2017, harvesting was underway and Landing 8, and felling was underway from Landing 9 and road lining operations were underway to Landing 10.
3. By the 12th of December 2017, all landings were in place to Landing 13 and trees had been felled (ultimately to waste) from Landing 10. At some stage soon after the 12th of December 2018 all operations ceased in the forest.
4. While migration of slash from all landings was ubiquitous the key landings that resulted in significant harvest residues mobilising to waterways were Landings 5 through to 11.
5. The most significant failure and the one the resulted in the loss of the majority of the harvest residues that had been stored on site was Landing 9 which had a debris flow travel at least 550 metres down into the true left tributary of the Waihora Stream.
6. High resolution satellite imagery allowed for the harvest residues to be traced downstream to as far as Kanakania Road and this could be verified by subsequent on the ground site inspections.
7. Harvest residue practices in Makiri Forest were generally poor with all sites having birds-nests of slash perched on the edges of landings.

Some of these birds nests were corduroy or logs used as retaining posts (Landing 11) or with fill material laid over the top of a birds nest to make a wider working space (Landing 8).

References

Cave. M. P. (2018a)

Cave. M. P. (2018b)

Cave. M. P. (2019) Analysis of landslide events in the Wakaroa and Makiri Forests, and adjacent areas. 36 p. 1 Appendix.