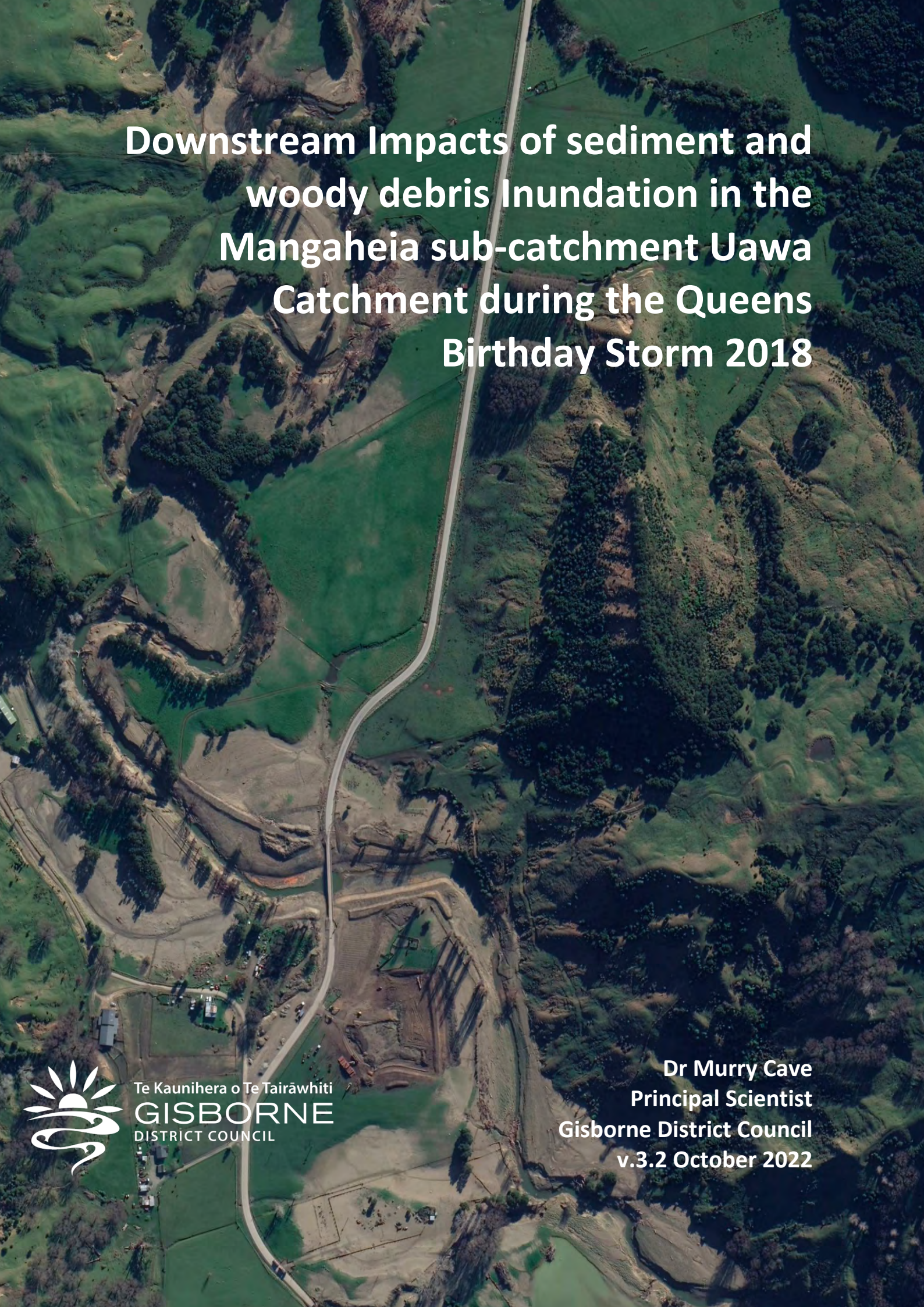

Downstream Impacts of sediment and woody debris Inundation in the Mangaheia sub-catchment Uawa Catchment during the Queens Birthday Storm 2018

Dr Murry Cave
Principal Scientist
Gisborne District Council
v.3.2 October 2022

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Executive Summary
Woody debris has been tracked from the Mangateao and Mangatoitoi streams in Uawa Forest to as far as the confluence of the Mangaheia with the Uawa River. Given that logs and woody debris generally managed to traverse the entire river, it is highly likely that logs from Uawa forest also contributed to the material washed up at Tolaga Bay beach along with material from other forests. Pine, much of it having some degree of harvest processing (cut logs) dominated the woody debris within both the Mangaheia and wider catchment. There were contributions from other sources, particularly from Arakihi, but these were relatively insignificant compared with the quantities that can be traced back to the Mangateao and Mangatoitoi streams.

The area covered by sediment downstream is significant with the sediment covering at least 223.5 Ha, however, much of the sediment will have remained in the river as both suspended and bedload sediment until it reached the sea at Tolaga where a significant sediment plume continued for some time. Large log jams have an impact on bed sediment composition and biota via complex water flow-sediment-wood interactions. Log jams within rivers can strongly alter channel hydraulics and sediment transport, forcing a change in channel morphology. Thus the impact of woody debris on the river can be more than the obvious impact of damage to pastures and the need for removal. The woody debris can also directly cause river bank erosion exacerbating the loss of sediment from the river channel and accelerating meander channel migration potentially causing long term loss of productive land.

Direct damage to properties downstream of Mangateao and Mangatoitoi streams was significant, with both sediment and woody debris deposited, pasture losses and damage to fences. Damage from deposition of sediment and woody debris was also significant for properties below Willowbank Forest and was widespread on Paki Tangohau's property.

Wigan Bridge acted as a debris dam and this resulted in areas on Takapau road being inundated with sediment as a result of elevated water levels behind the dam. The bridge was, however, an ineffective barrier and did not stop woody debris from reaching the lower catchment. The log jam raised water level upstream to the extent that debris-laden flood waters were able to bypass both the north and south abutments of the bridge.

This can be seen downstream of Wigan bridge where debris laden flood waters inundated land on either bank discharging both sediment and woody debris. Woody debris lodged against trees on the riparian margin and against fences. This acts to deflect flows and causes localised backwater effects raising water levels in the vicinity (the process of afflux). The load of woody debris on fences can cause them to fail and broken fences were observed particularly on the true left bank of the Mangaheia between Wigan and Paroa Road bridges. Broken fences were also observed on Mangaheia Station on the south side of Tauwhareparae Road well away from the river.

In this stretch of river, ephemeral log jams in the active meander system are likely to have exacerbated overtopping directing water onto the low-lying flood plan. This is particularly evident on the Jefferd property upstream of the Warburtons, through the Warburtons citrus orchard and downstream paddocks, and on the Kerslake property where a maize crop was damaged. On the Kerslake property the breakout of debris-laden flood waters is clearly associated with a sharp meander bend. This was also the case immediately upstream of the

Paroa Road bridge where sediment and woody debris-laden flood waters broke out in two stretches; one directing flow across the Simpson property and then onto Mangaheia Station and the other onto the Mangaheia 2D block and then onto the Broadlands/Parker property. Fencing and the bridge abutments on Paroa Road caught much of the woody debris and the Broadlands/Parker property and the Halley dwelling were mainly affected by sediment-laden flood waters. This was likely exacerbated by the woody debris induced river bank scour.

Downstream of the Paroa Road bridge the volume of woody debris decreased largely because of the widening of the flood plain which would have reduced inundation depths and flow velocities. Sediment deposition still occurred but was more confined to areas close to the river as a result of reduced water velocities. Two low-lying former meandering bends on the Broadlands farm downstream of the Paroa road bridge were particularly affected.

Woody debris emanating from Uawa Forest was not the only impact and the large number of landslides within the forest resulted in a significant volume of sediment being discharged into the catchment. Sediment deposition is evident in both the aerial and satellite imagery acquired soon after the flood and is particularly evident in the photographs of both the Mitchell and Parker properties (**Figure Forty Seven**). Sediment deposition affected all of the downstream properties, however, not just those figured in the report.

Ecological effects

No assessments of ecological effects have been undertaken in the Mangaheia main stem itself. Reports were undertaken on the ecological affects in Mangatoitoi stream within the forest, in Kaitawa stream/estuary, and in the littoral zone at Tolaga Bay but these cannot be directly linked to the Mangaheia.

Uawa forest has now been replanted and the degree of vulnerability to landsliding should diminish over time. Phillips, *et. al* (1996), for example, cite a window of vulnerability of two to six years. An analysis of satellite imagery between 2019 and 2022 has demonstrated that the forest remains vulnerable 4 years later and some major landslides ranging from 1 to 3 Ha occurred within the forest within two years after the 2018 storm. It is anticipated that when this forest is next harvested in 25 years or so, mitigations within the forest as well as downstream will reduce the potential for impacts such as was seen in 2018.

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Table Of Contents

Figures

Introduction

The impacts of the failures in Uawa Forest on downstream communities are as follows.

- Deposition of sediment on land as a result of landslides from within the forest boundary,
- woody debris discharged from consent boundary onto downstream properties, and the beaches at Tolaga Bay
- damage to fences, crops and pasture, and
- flood spread.

Flooding in itself, is not an impact that relates to the Uawa Forest discharges except where log jams in the river have resulted in back flooding which is where the log jams raise water levels above what would otherwise have been in the flood. Logjams can also divert water into properties which would otherwise not have flooded and cause scour of the riverbanks which can result in property loss. For this reason, flooding in the absence of woody debris influx has been discounted here.

Sediment deposition was exacerbated by the large number of landslides in the forest and results in the loss of pasture, and reduced access/trafficability in paddocks. Woody debris is a more tangible impact. Not only does it produce areas where the debris needs to be picked up but disposal also becomes and issue. A significant effect of woody debris is the loss of or damage to fence lines.

Sediment deposition

Sediment deposition affected many of the properties downstream to varying degrees as summarised in yellow in **Figure One** but shown in greater detail in following figures. Sediment deposition remains obvious for months later but does not relate directly to the flood spread which would be greater (**Figure Two**).

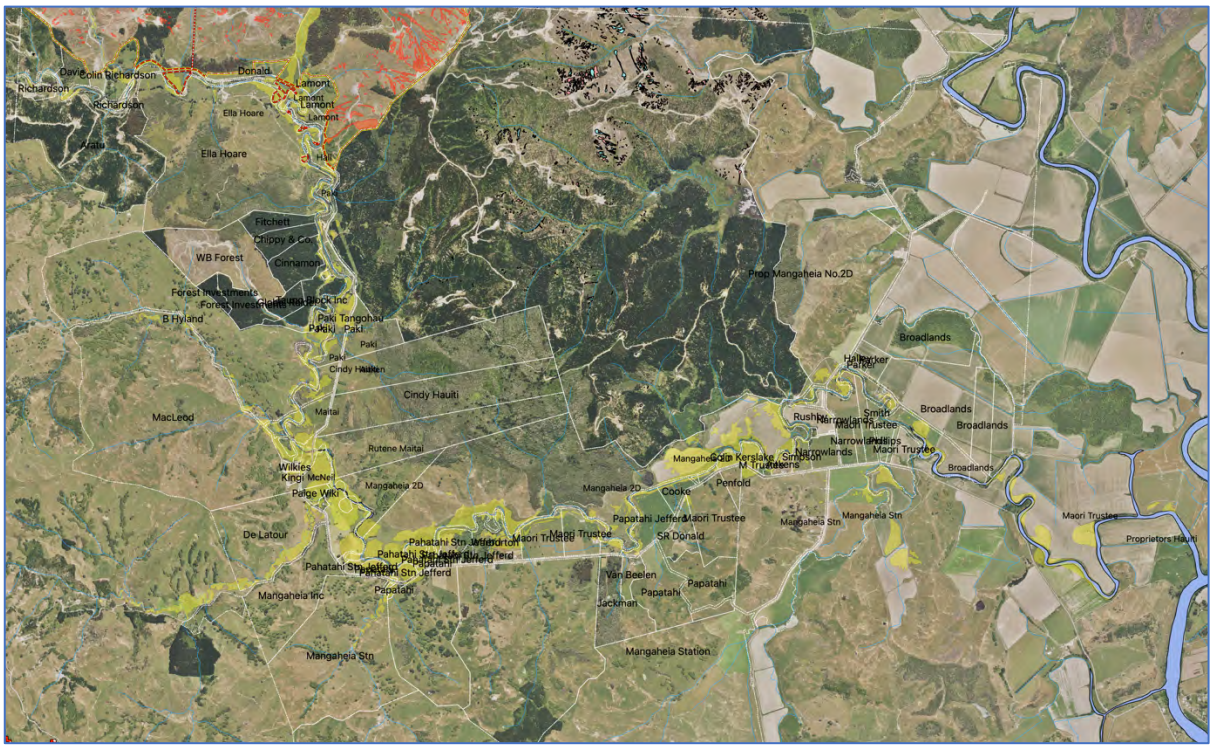

***Figure One**. Sediment deposition in the Mangaheia Catchment downstream of the Uawa Forest based on Sentinel and Maxar satellite imagery (in yellow).*

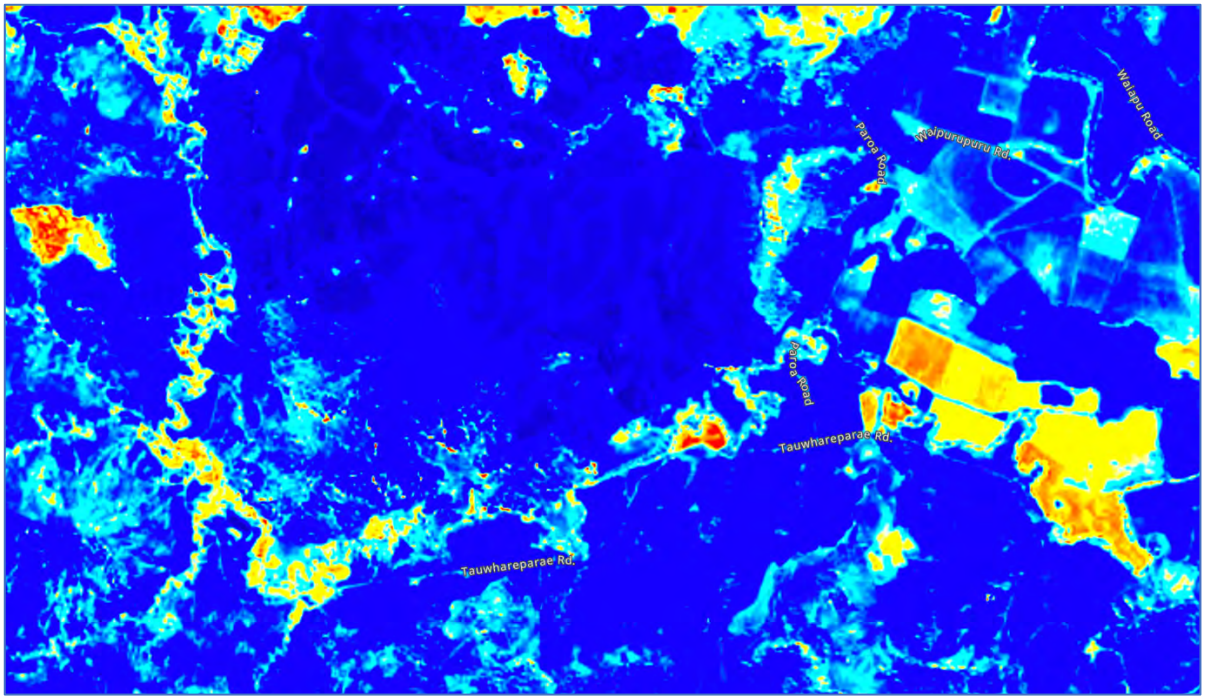

Figure Two. *Sentinel image dated 15th June 2018 showing the moisture index (reds and yellows are bare ground) which equates to recent sediment on the flood plains while pale blue areas are areas of elevated moisture which equates approximately to the flood spread. As this indicates, most of the riverside properties in the Mangaheia still showed the residual impact of flooding a week or so later.*

Woody Debris deposition

There was extensive deposition of woody debris from the Uawa Forest along with other forests in the Uawa Catchment (cf. Paroa and Te Marunga). The composition of this material was assessed and was found to be comparable to Cyclone Cook (*cf* Cave *et. al* 2017) with 13% cut pine, 54% long resident (weathered) pine logs and 17% pine with root balls (windthrow or eroded from riverbanks. Willow and poplar (12% and indigenous wood (4%) was a minor component (**Figure Three)**. The distribution of woody debris in the Mangaheia catchment below the Uawa Forest is shown in **Figure Four** below.

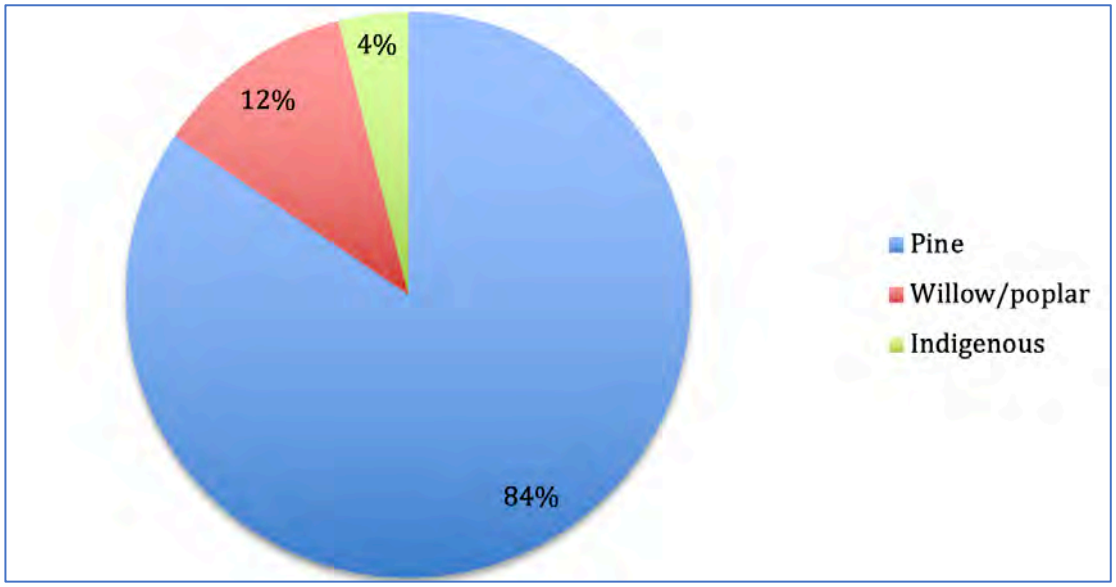

Figure Three. *Aggregate woody debris composition 2018 Queens Birthday storm, Uawa catchment.*

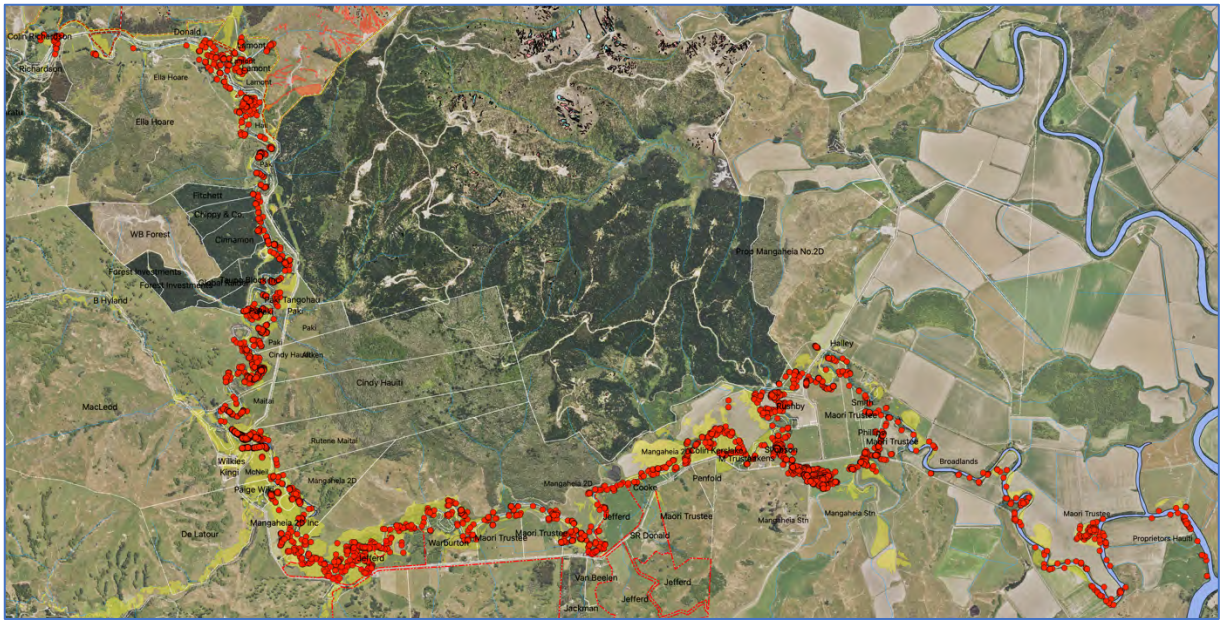

Figure Four. *Woody debris distribution (red dots) and sediment deposition (yellow) in the Mangaheia Catchment downstream of the Uawa Forest based on Sentinel and Maxar satellite imagery. The various property owners are also shown and these are described in more detail below.*

Detailed assessment by property

The following figures document the degree of sediment and woody debris deposition at specific groups of properties downstream from Uawa Forest.

Mangateao Confluence

The Richardson property sites at the junction of the Mangateao stream with the Mangaheia River and experienced extensive damage because of an inundation of sediment and woody debris. The general extent of sediment deposition and woody debris distribution based on post event Sentinel and Maxar satellite imagery is shown in **Figure Five** below and documented further in **Figures Six to Eight** below.

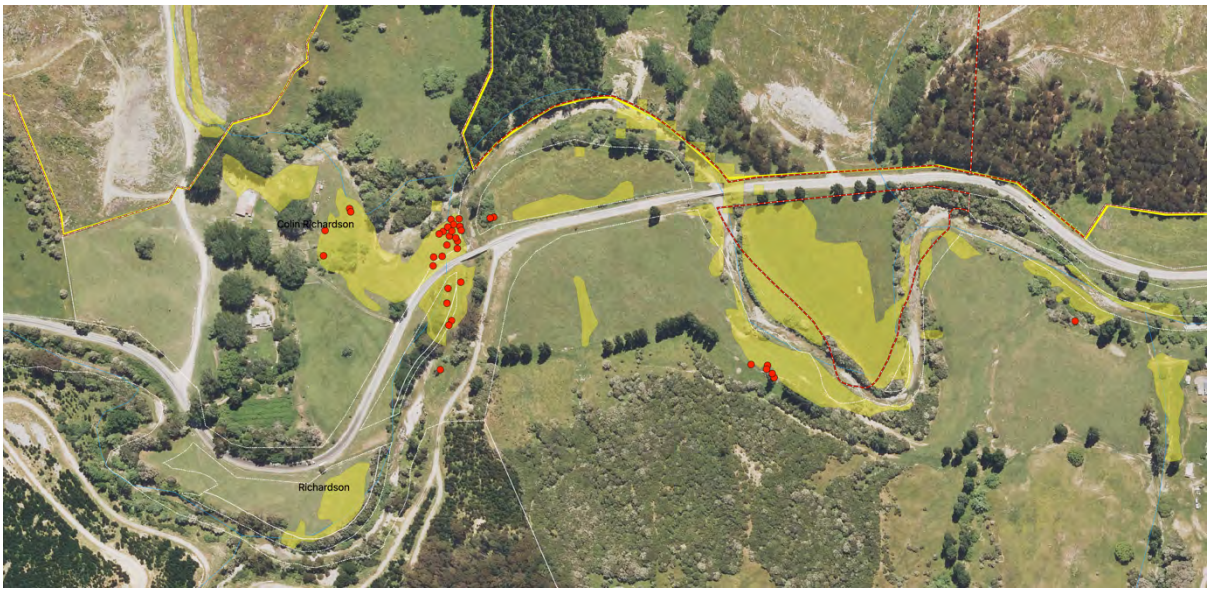

Figure Five. *View of the Richardson property on the confluence of the Mangateao and Mangaheia showing the sediment deposition and woody debris deposits based on Sentinel and Maxar satellite imagery.*

Figure Six. *Aerial view of the east end of the Richardson property adjacent to the Tauwhareparae Road (6th June 2018) showing the extensive woody debris and sediment deposition.*

Figure Seven. *Aerial view of Richardson property (6th June 2018) showing the extensive woody debris and sediment deposition. As noted above the flood height is more extensive than the sediment deposition and this image shows evidence of flood inundation through the buildings.*

Figure Eight. *13th July 2018 Maxar Satellite image of the Richardson property showing the sediment deposition and woody debris distribution.*

Mangatoitoi Confluence

The Mangatoitoi stream joins the Mangaheia River approximately 1.5km downstream of the Mangateao. There are multiple properties at the confluence but not all were adversely affected by the discharges from Uawa Forest. The Donald property upstream of the Mangatoitoi on the true left bank of the Mangaheia was not affected by the storm apart from some overland flow from the slopes to the north. The Hoare property opposite the confluence on the true right bank of the Mangaheia experienced significant sediment deposition as well woody debris. The Lamont property was significantly affected but properties immediately downstream from there were not as significantly impacted (**Figure Nine**).

The Lamont property is situated on the true left bank of the Mangatoitoi at the confluence and includes a dwelling situated on a spur but also an adjacent stream and river flats used to livestock grazing as well as land on the banks of the Mangatoitoi north of Taujwhareparae Road. The dwelling on the spur was unaffected but the adjacent stream experienced a significant discharge of woody debris from Uawa Forest while significant woody debris in the stream within the Uawa Forest at the boundary was not removed and posed a potential ongoing threat. Woody debris in this stream also formed a log jam immediately above Tauwhareparae Road. This was cleared to relieve pressure on the bridge but a large volume of woody debris remained in a vulnerable position on the banks for some time (**Figure Ten**).

A considerable number of logs were also distributed through the property on the banks of the Mangatoitoi (**Figure Eleven**). These were put into piles within a month but not removed until some months later. Other woody debris on the hydro reserve and on the Hoare property was put into piles by July 2018 but not removed until early 2019 (**Figure Twelve**).

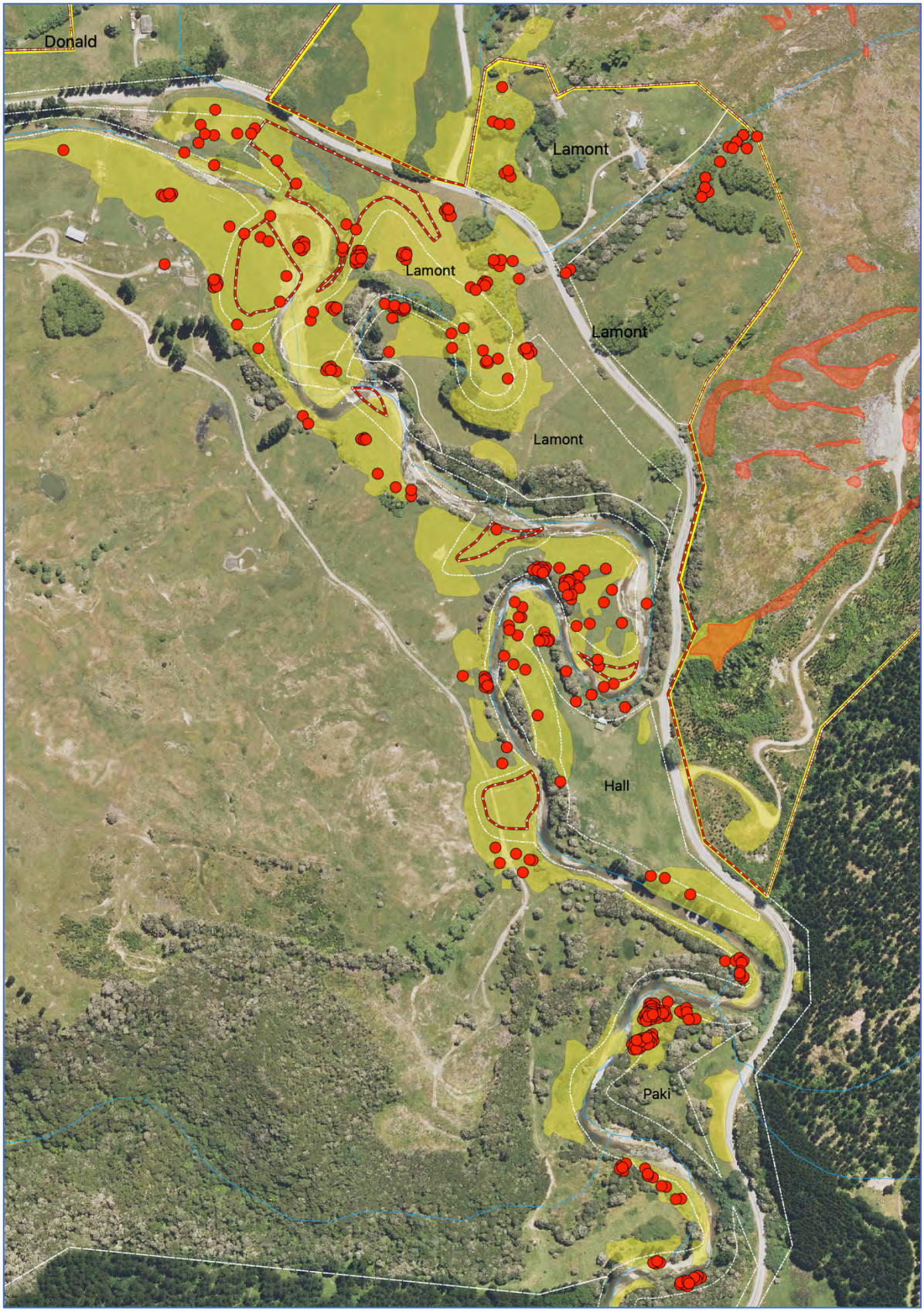

***Figure Nine**. Sediment deposition and woody debris distribution immediately downstream of the Mangatoitoi tributary. The Lamont property experienced significant woody debris deposition along with loss of pasture and damaged fences. Ella Hoare's property on the true right bank of the Mangaheia had extensive woody debris deposition.*

***Figure Ten**. Woody debris pulled back from small stream on Lamont property but perched in a vulnerable position rather than removed (30th June 2018).*

***Figure Eleven**. Woody debris on the banks of the Mangatoitoi stream, Lamont property 10th June 2018.*

Figure Twelve. *Satellite image of the confluence of the Mangatoitoi and Mangaheia dated 13th July 2018 showing the sediment deposition and areas of wood piles. Those marked by a white arrow are on the Lamont property, those in red on the Hoare property while those in green are on hydro reserve. Other wood piles at the top of the image and immediately above the white arrow on the right are within Uawa forest. The woody debris above the righthand white arrow along with the woody debris remain in place and remains a potential reservoir of woody material that can be remobilised in a subsequent storm.*

Tangohau Stretch

South of the Lamont property is a narrow area of river with scattered woody debris but there is a pronounced increase in both sediment deposition and woody debris where the river again opens up (**Figure Thirteen**). The main landowner in this area is Paki Tangohau who experienced significant adverse effects from the storm event (**Figure Fourteen**). Despite being in the area that experienced heavier rainfall that in Uawa forest, there are no obvious landslides or sediment discharges in this area with all impacts associated with the discharges that occurred upstream.

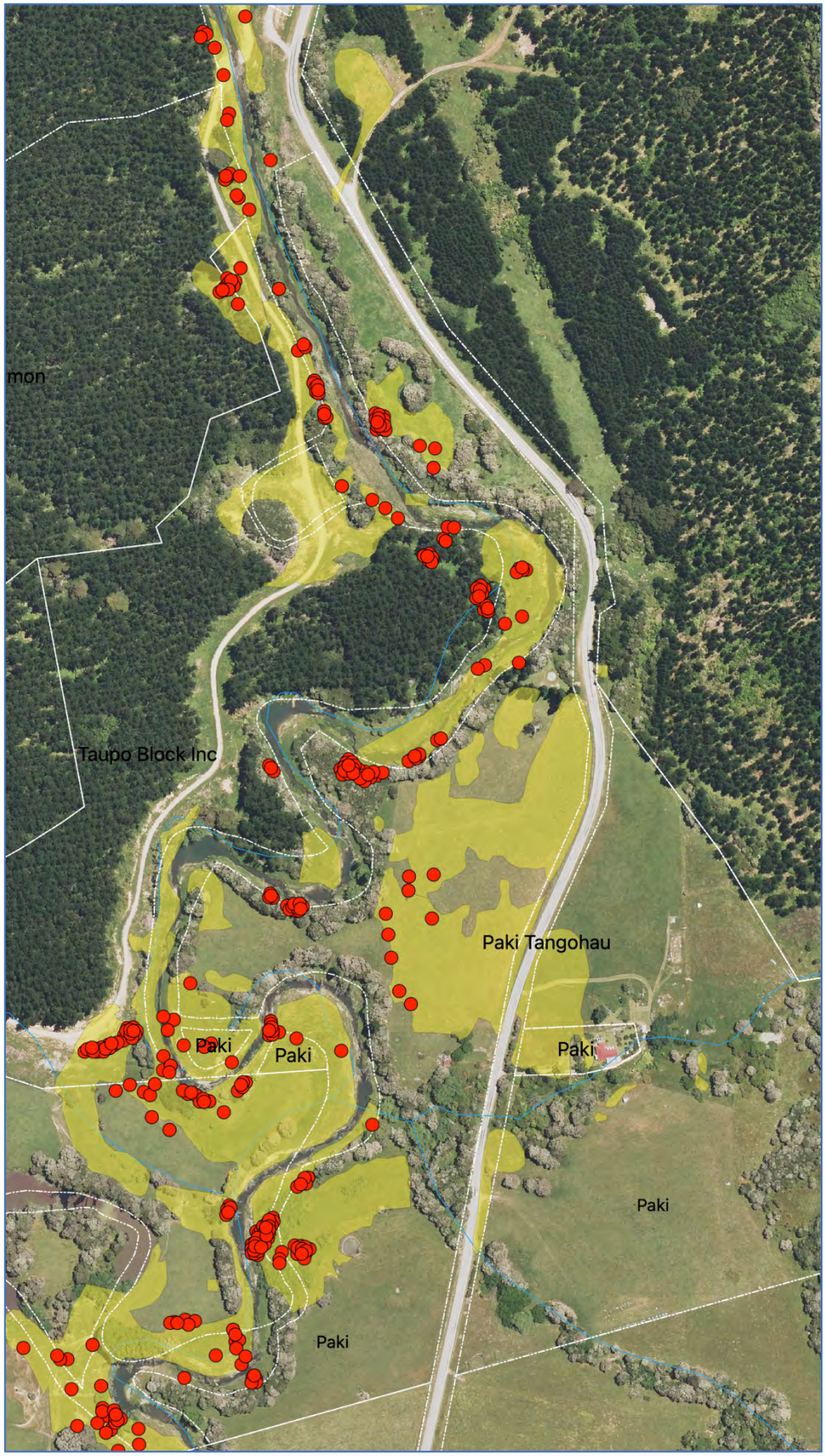

***Figure Thirteen**. Sediment deposition and woody debris distribution on Paki Tongohau property north of Wigan Bridge. Some of the woody debris bottom left is on the Hyland property. Flood water back up due to the Wigan bridge log jam and smaller log jams upstream exacerbated flood spread on the Tangohau property.*

Figure Fourteen. *Aerial view of the Tangohau property (17th July 2018). The thick sediment deposition is obvious as is the woody debris adjacent to the river (middle right) and elsewhere. Close to Tauwhareparae road some piles where woody debris has been cleared but at top left scattered woody debris remains.*

Wigan bridge area

Between the Tangohau property and Wigan bridge, the flood plain widens further and there is a corresponding expansion of sediment deposition especially close to the bridge itself (**Figure Fifteen**). It was not possible to undertake an analysis of the woody debris at Wigan bridge as the priority was to remove the debris built up against the bridge as fast as possible to reduce the risk to the bridge. None-the-less the satellite imagery (**Figure Sixteen)** along with drone, aerial and ground assessments undertaken soon after the Queen's Birthday storm means we have a good understanding of what occurred.

What happened at the bridge is key to understanding the impacts both above the bridge and downstream. Firstly, did the bridge act as a large slash catcher meaning that little woody debris migrated past the bridge to the lower catchment? Secondly what was the impact of the woody debris dam at the bridge on flood levels.

It has been contended that the bridge acted as a large slash catcher and prevented the migration of woody debris downstream. As is obvious from **Figure Four** above, however, woody debris has been mapped from below Wigan bridge to the confluence of the Mangaheia river with the Uawa river. Wigan bridge is, however, ineffective as a debris catcher. While the woody debris does act as a dam once it builds up there would have been a significant volume of woody debris pass under the bridge before the dam forms. Secondly, because of the log dam that forms (**Figure Seventeen**), the water level upstream rises (**Figure Eighteen**) which increases the area flooded above the river exacerbating sediment deposition in this area (this is known as afflux). Additionally, this results in woody debris being able to pass downstream

via over topping of the bridge deck as well as bypassing via the bridge approaches. Wigan bridge is one location where the afflux or back-flood impact of the log dam is obvious. Using the 2018-19 regional LiDAR contours suggested a significant overtopping height but contours generated from a subsequent drone map indicated an overtopping of between 1.5 and 2m above the bridge deck (**Figure Nineteen**, see discussion below).

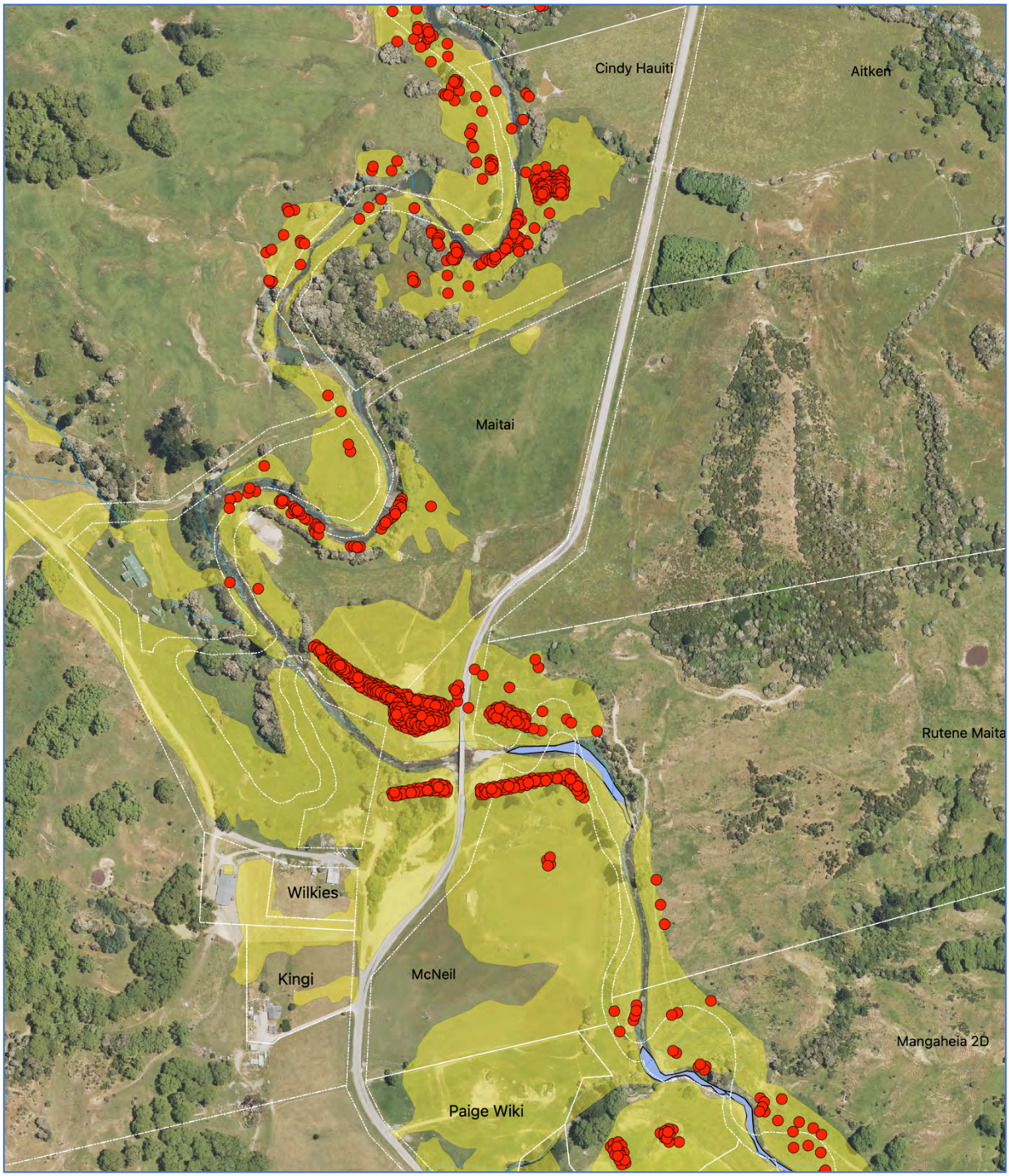

***Figure Fifteen**. View of the sediment deposition and woody debris in the vicinity of Wigan Bridge. A large volume of largely pine woody debris has been placed in piles on road reserve, and on the McNeil property downstream and on the Maitai property upstream. Woody debris on the Mangaheia 2D block is shown at bottom right and there is extensive woody debris on Cindy Hauiti's property at top*

Figure Sixteen. *Maxar satellite image of the Wigan Bridge area (13th July 2018) showing the extent of sediment deposition. The stopbanks above and below the bridge are areas of logs covered in sediment.*

Figure Seventeen*. Aerial image of Wigan Bridge (6th June 2018). Note the woody debris downstream at bottom right and left (in shadows).*

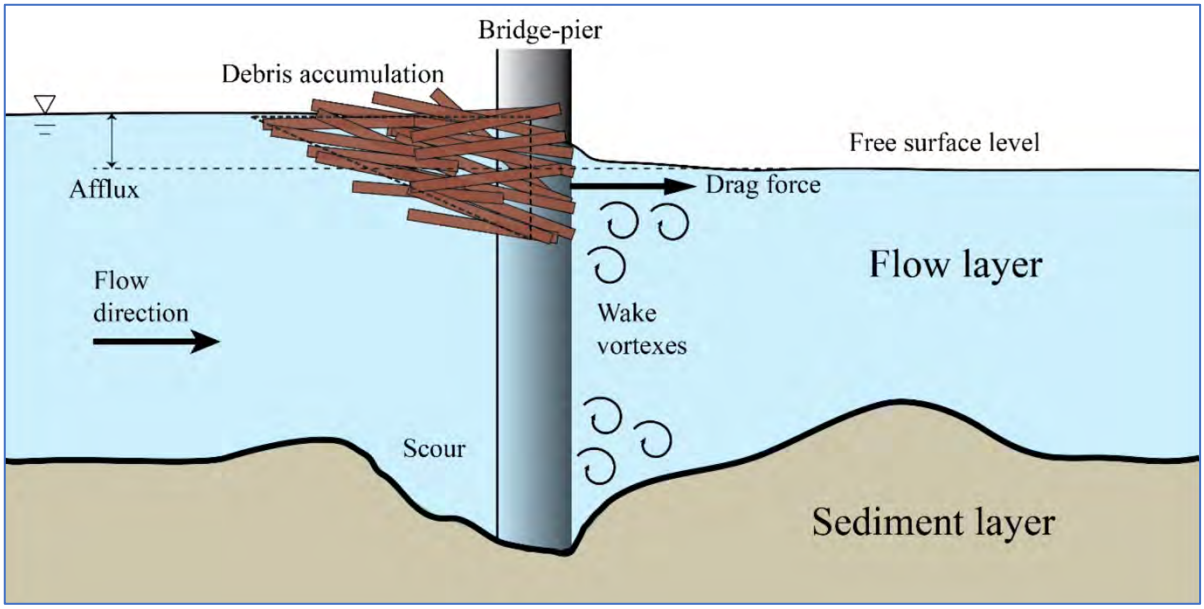

Figure Eighteen. *Diagram showing the impact of woody debris jams against bridges (From Cantero-Chinchilla, et. al (2018) Assessing the effects of debris accumulations against river bridges. A key element is the afflux that results which exacerbates flooding upstream.*

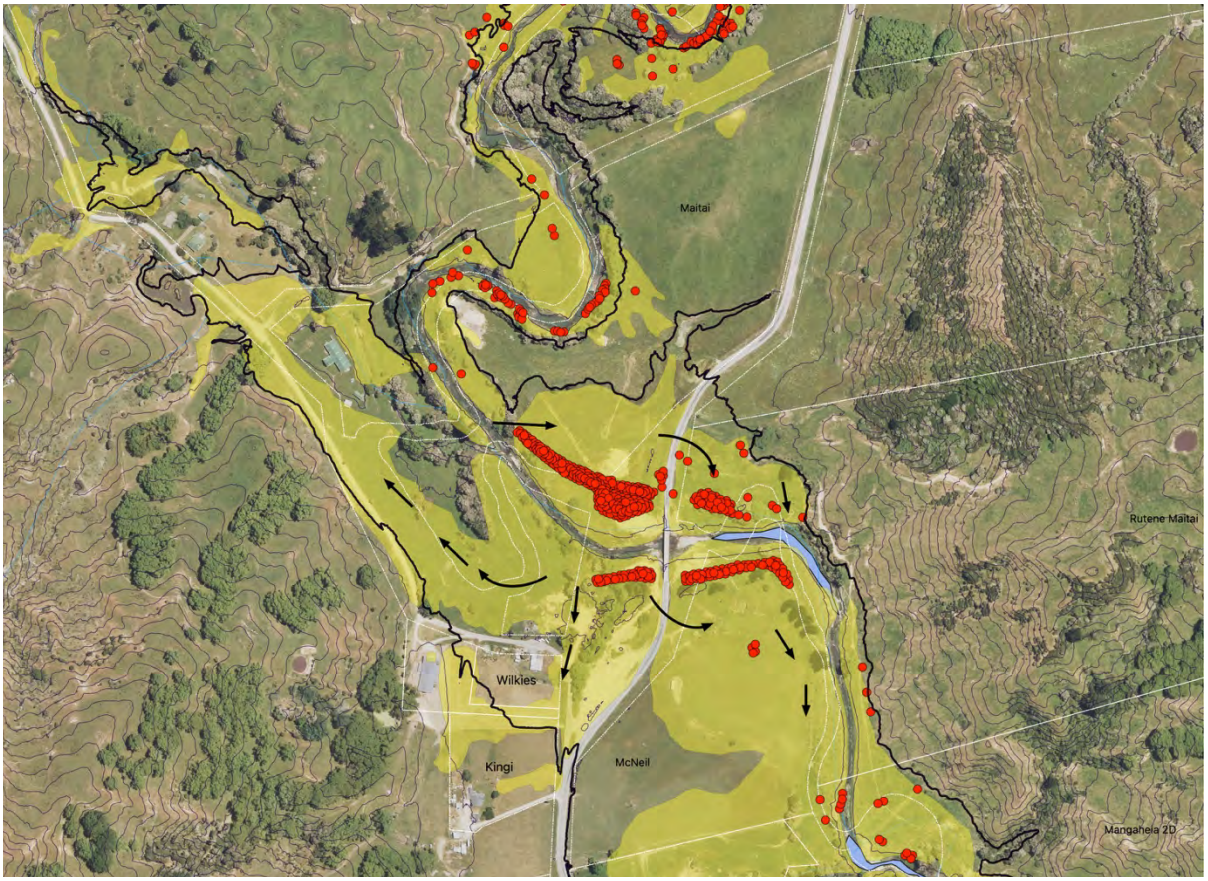

Figure Nineteen. *Detail of Figure Fifteen with the LiDAR based contours (solid black line) which aligns closely with the sediment deposition at Wigan Bridge (the actual flood spread would have been more extensive) showing that the bridge would not have been effective in stopping woody debris migrating downstream. Afflux caused by the woody debris exacerbated back flooding in Takapau Road and lead to inundation of properties.*

The back flooding on Takapau Road cause by the woody debris at Wigan Bridge is shown in **Figures Twenty** and **Twenty One** below while the flood bypass on the true left back at Wigan Bridge is shown in **Figure Twenty Two**.

Figure Twenty. *Aerial view looking up Takapau Road from above Wigan Bridge (6th June 2018) showing the sediment deposition where the Mangaheia overtopped the bank and inundated low lying areas. Afflux due to the woody debris dammed against the bridge exacerbated flood inundation in this area.*

Figure Twenty One. *View looking towards Wigan Bridge looking along Takapau Road (9th June 2018). One inundation pathway from the Mangaheia is on the far left. Woody debris transported from the Mangaheia is visible against the fence in middle ground. The low lying building (background right) was inundated during the storm.*

Figure Twenty Two. *Aerial view showing Wigan Bridge (9th June 2018). The area on the true left bank of the river where overtopping allowed woody debris to migrate downstream.*

Below Wigan bridge to Warburtons

The area affected by sediment deposition and woody debris distribution for the area below Wigan Bridge with the affected land owners indicated is shown in **Figure Twenty Three** below. The main properties in this area comprises the Mangaheia 2D block (true left bank and true right bank top left), the Jefferds/Papatahi Station (middle) and the Warburtons (right). The Maxar satellite imagery on which the analysis presented in **Figure Twenty Three** is based is shown in **Figure Twenty Four**.

A helicopter overflight on the 6th of June 2018 documented the extent of damage in this vicinity and **Figures Twenty Five to Thirty** documents the distribution of woody debris and deposition of sediment that occurred. What is clear is that while there was a lot of woody debris caught up against Wigan Bridge, this did not prevent the logs from migrating past into the lower catchment. In **Figure Twenty Five** there are several wood piles evident but these relate to wood that migrated out of Uawa Forest during Cyclone Cook in 2017. Other woody debris, particularly on the left and top of the image are fresh, however, and were deposited during the Queens Birthday Storm. The inundation was not unexpected as the area is low lying and is inundated in floods regularly.

In **Figure Twenty Six**, an extensive area of flooding and sediment deposition is evident and there is a considerable amount of fresh woody debris caught up against willows on the river bank and notably there is a fence which has been severely damaged on Mangaheia 2D land.

In **Figure Twenty Seven** downstream of the area in **Figure Twenty Six**, there is further fresh woody debris caught against Mangaheia 2D land as well as considerable sediment deposition and some woody debris on Papatahi Station now owned by the Jefferds. In **Figure Twenty Eight** details of sediment deposition along with woody debris and a damaged fence is evident on Papatahi Station. Sediment deposition and distributed woody debris on both Mangaheia 2D and Papatahi Station downstream of **Figure Twenty Eight** is shown in **Figure Twenty Nine** while **Figure Thirty** shows extensive fresh woody debris and sediment deposited on Mangaheia 2D land adjacent to the Warburton property. The Warburton's experienced sediment deposition with woody debris mainly adjacent to the river (**Figure Thirty One**).

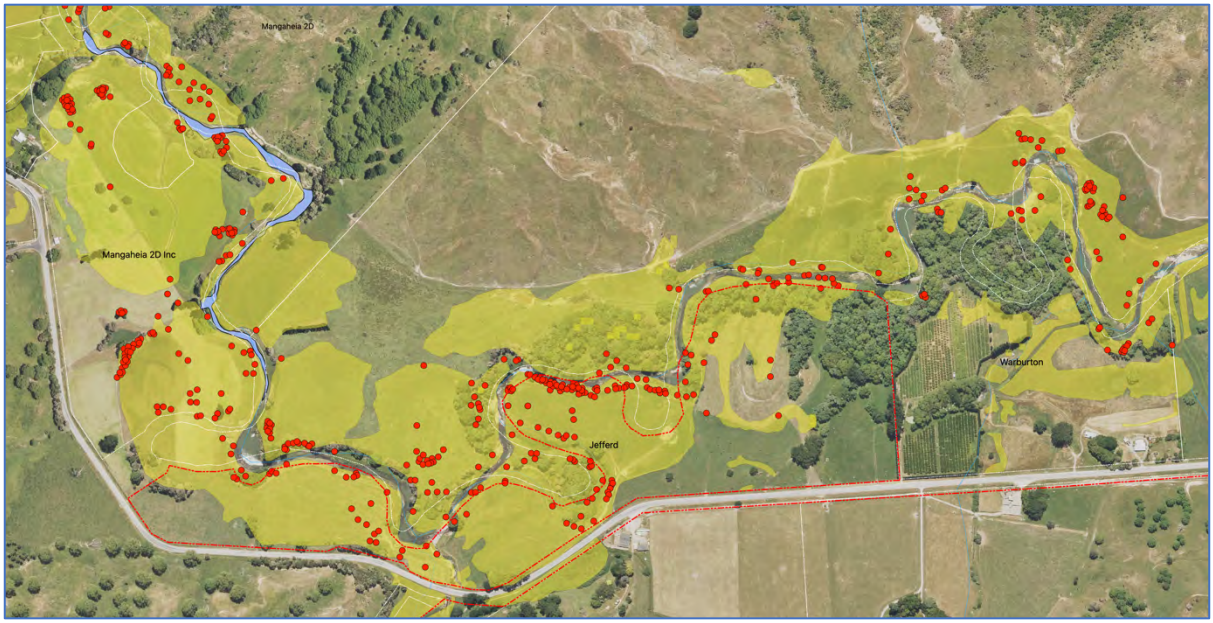

***Figure Twenty Three**. View of the area downstream of Wigan Bridge showing the sediment deposition and largely pine woody debris deposition on Mangaheia 2D Block (true left bank of the Mangaheia and bottom left, the Jefferd property (outlined in red), and the Warburton property (bottom right).*

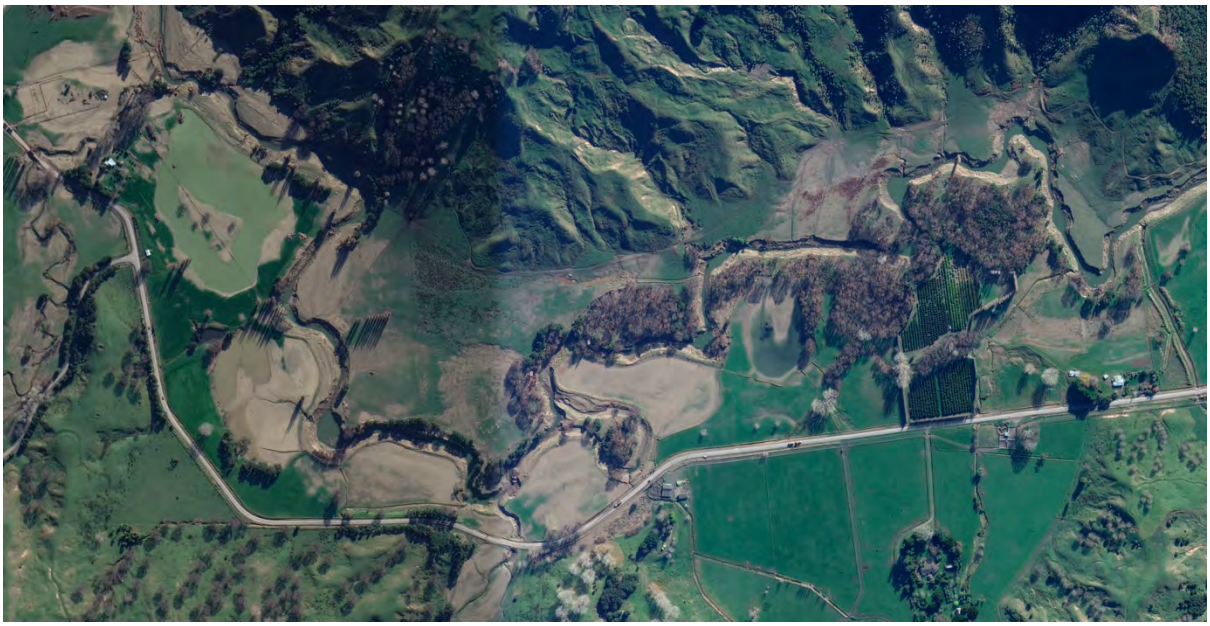

***Figure Twenty Four.** Maxar satellite imagery of the area shown in **Figure Twenty Two** showing the obvious sediment deposition from the Queens Birthday storm.*

***Figure Twenty Five**. View of Mangaheia 2D land on the true right bank of the Mangaheia adjacent to Arakihi Road showing wood piles from Cyclone Cook in 2017 (red arrows) and woody debris from the Queens Birthday 2018 event (White arrows).*

***Figure Twenty Six.** View of a damaged fence (bottom middle) and woody debris caught against trees on the banks of the Mangaheia as well as sediment deposition on paddocks of Mangaheia 2D land. The line of poplars are 900m below Wigan Bridge (see middle left in **Figure Twenty Four**).*

***Figure Twenty Seven**. View further downstream from **Figure Twenty Six** showing woody debris and sediment deposition on Mangaheia 2D land (true left) and Jefferd property (true right) banks of the Mangeheia.*

***Figure Twenty Eight**. View looking upstream from above Warburton property showing the sediment deposition, broken fence (bottom right arrow) and woody debris on the Jefferd property. The inundated area in **Figure Twenty Five** is visible at top right.*

***Figure Twenty Nine**. View looking downstream with Tauwharepare Road at top showing sediment deposition and woody debris on the Jefferd property (Papatahi Station) and on Mangaheia 2D land in the abandoned meander loop (middle).*

***Figure Thirty**. View of the true left bank of the Mangaheia adjacent to the Warburton property (true right) showing sediment deposition and woody debris.*

***Figure Thirty One**. View of the Warburton property (True right side of river) showing sediment deposition through the middle of the property and also through part of the citrus orchard (arrowed). Overall there is little woody debris evident except for at the downstream end of the property (arrowed) this is likely due to woody debris being caught up in the extensive willows on the banks of the river in this area.*

East of Warburtons to Cooke property

East of the Warburton property, the flood plain of the Mangaheia broadens and much of the sediment deposition has occurred close to the river and woody debris is distributed close to the riverbanks across the entire stretch of river (**Figure Thirty Two**). A meander loop in the middle of this section (Mangaheia 2D) has sediment deposition and was most likely fully inundated by the flood (**Figure Thirty Three**) as was the Maori Trustee/Mitchells property upstream (**Figure Thirty Four**) which also experienced extensive sediment deposition (**Figure Thirty Five**).

Aerial images from the 6th June also indicates that extensive deposition of woody debris occurred on this meander loop (**Figure Thirty Five**). The land on the true right bank upstream occupied by the Mitchell family appears to have been partially protected from sediment deposition by a stopbank although some logs were deposited between the stopbank and the river as well as against a fence close to the house (see **Figure Thirty Three**).

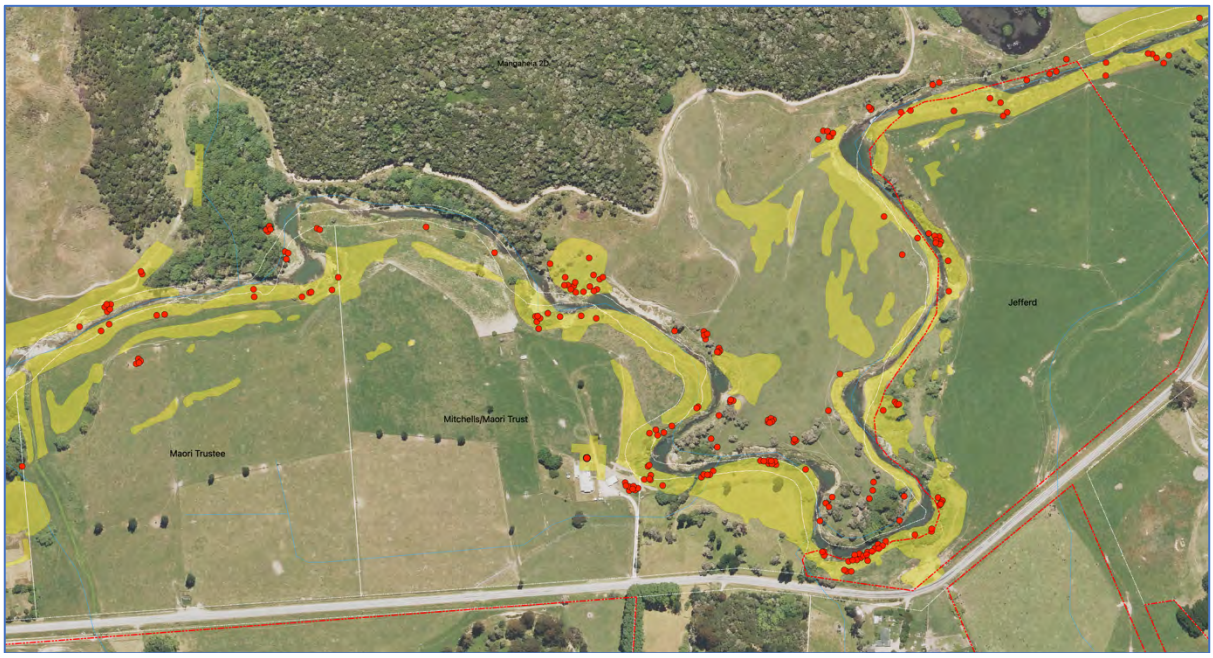

Figure Thirty Two. *View of area between the Warburton properties and the downstream Cooke property showing the sediment deposition and woody debris deposited on the Mangaheia 2D block, the Jefferd paddock and on land administered by the Maori trustee. The dwelling in the middle was occupied by the Mitchells.*

Figure Thirty Three. *Maxar satellite image of the area shown in* ***Figure Thirty Two*** *showing the areas of sediment deposition. A wood pile can be seen close to the river in middle right. The dwelling in the middle of the image was occupied by the Mitchell family.*

Figure Thirty Four. *Screenshot from a video of the Mitchell dwelling taken during the rescue of the family showing the extent of flooding. Media reports indicated that the occupants were on the table to get above the water and were considering breaking into the ceiling to escape the flood waters when they were rescued.*

Figure Thirty Five. *Photo of the Mitchell dwelling taken after the storm showing the extent of sediment deposition within the dwelling. (Photo. Gisborne Herald)*

Figure Thirty Six. *Aerial image (6th June 2018) looking upstream with the meander in the foreground (Mangaheia 2D) with considerable woody debris spread across the field. This material was subsequently gathered into the wood pile visible in* ***Figure Thirty Three****. The fields on the true right bank (top) do not appear to have been as significantly affected but there are still signs of sediment deposition and scattered individual logs. The Mitchell dwelling (top middle) experienced significant sediment deposition.*

Kerslake Property to Paroa Road

This section of river was significantly impacted by sediment deposition and woody debris. Inundation and sediment deposition damaged a maize crop on the Kerslake property on the true right bank (**Figure Thirty Seven**) while further downstream a significant discharge of woody debris occurred on the Simpson property. The Mangaheia 2D block on the true left bank experienced sediment deposition with some woody debris deposited while the Rushby property on the true right bank downstream of the Simpson property had both sediment deposition and a large amount of woody debris deposited. One property between the Simpsons and the Rushby properties, now known as Narrowlands appears to have had only minor impacts (**Figure Thirty Eight).**

At the bottom right of **Figure Thirty Eight** a small part of Mangaheia Station is visible and this area experienced significant woody debris discharge from the flow directed across the Simpson property. Downstream of the Rushby property woody debris was deposited along the riverbanks and on road reserve against the abutments to the Paroa Road bridge. There were no indications of a log jam downstream of where the significant discharge of woody debris occurred but there is a tight meander bend immediately downstream which has an extensive cover of mature willows which would have reduced the conveyance capacity of the river at this point (**Figure Thirty Nine**). A Maxar Satellite image showing the discharge point is shown in **Figure Forty**.

Figure Thirty Seven. *Aerial view dated 6th June 2018 of the Mangaheia 2D property (left and bottom) and the Kerslake property (top middle). Extensive sediment deposition has occurred on both properties and there is damage to maize crop on the Kerslake and small piles of woody debris are visible at top right.*

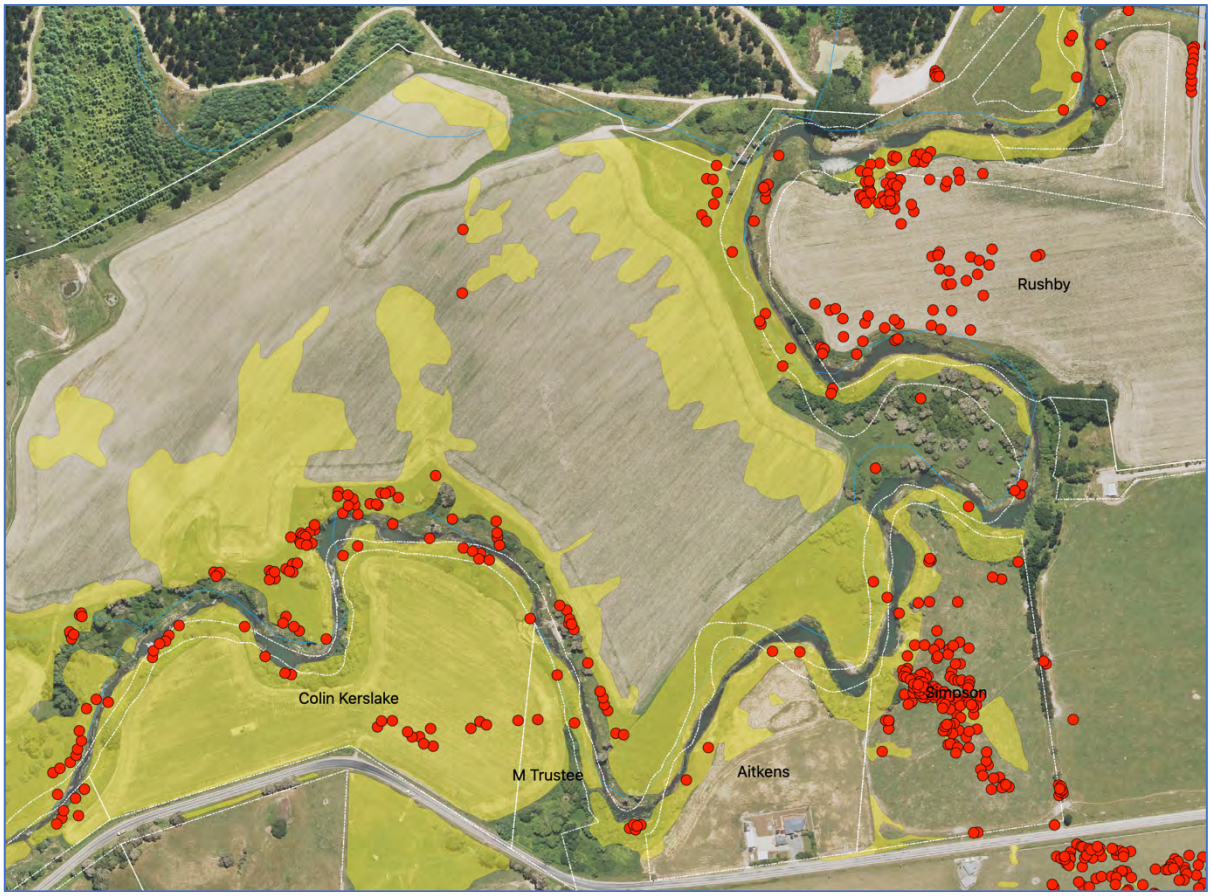

Figure Thirty Eight. *Properties north of Mangaheia Station showing the sediment deposition and distribution of largely pine woody debris. There was a significant amount of largely pine woody debris deposited on the Simpson property (bottom right) with lesser woody debris on the Kerslake property.*

Figure Thirty Nine. *Aerial view of the Simpson property (bottom left), and Rushby (top right) properties showing the distribution of largely pine woody debris. Sediment deposition and pine woody debris can be seen on the Mangaheia 2D Block. Flood flows may have been impeded by the tight meander and mature willows immediately downstream.*

Figure Forty. *Maxar satellite image dated 13th July 2018 of the Mangaheia 2D block (top), Kerslake property (bottom left), Aitken property (bottom middle) and Simpson Property (bottom right). Sediment deposition is evident particularly on the Mangaheia 2D block which also has two wood piles. The line of wood piles evident on the Kerskale property were cleared up following the harvest of the maize crop damaged during the storm event. Woody debris remains where it was deposited on the Simpson Property.*

Mangaheia Station

Mangaheia Station is situated on the south side of Tauwhareparae Road well away from the Mangaheia river but was still affected by a significant volume of woody debris which migrated from the river at the Simpson property (**Figure Forty One**). This woody debris damaged fences and the pasture experienced sediment deposition (**Figure Forty Two**).

Figure Forty One. *Mangaheia Station showing the sediment deposition (yellow) and distribution of largely pine woody debris from the 2018 Queens Birthday storm.*

Figure Forty Two. *Aerial view of Mangaheia Station on 6th June 2018 showing the woody debris across the paddocks. Note the destroyed fences.*

Paroa Road Bridge and downstream-Broadlands & Halley

East of Paroa Road the Mangaheia flood plain widens out and eventually joins with the Uawa River main stem. Accordingly, flood capacity is improved, however, sediment and woody debris deposition still occurred (**Figure Forty Three**). Woody Debris is evident particularly on the true right bank of the river which has a variety of landowners including the Parkers, Smith's Phillips and the Maori Trustee.

Land on the true left bank was affected by sediment deposition and flooding and is largely owned by the Parkers with one flooded section belonging to the Halleys. Wood deposition still occurred on the true left bank but not to the same extent as the true right bank where woody debris was lodged against a fence line on the Phillips property. Aerial imagery from the 6th June 2018 does not suggest that a log jam at the Paroa Road Bridge exacerbated flooding or caused afflux (**Figure Forty Four**).

It is considered that the sediment and woody debris deposition resulted from the reduction in flood conveyance capacity in the meander belt system downstream of the Kerslake property which was likely exacerbated by ephemeral log jams which directed flood waters across low lying areas on the true left side of the river's flood plain (**Figure Forty Five**). Footage from news interviews with the parkers after the event as well as photographs supplied showed that significant sediment deposition was more widespread on the Parker property than was evident in either the satellite imagery or the 6th June helicopter flight. While much of the woody debris was slash rather than logs it still resulted in damage to both fences and farm gates (**Figure Forty Six**). Significant sediment was also deposited (**Figure Forty Seven**).

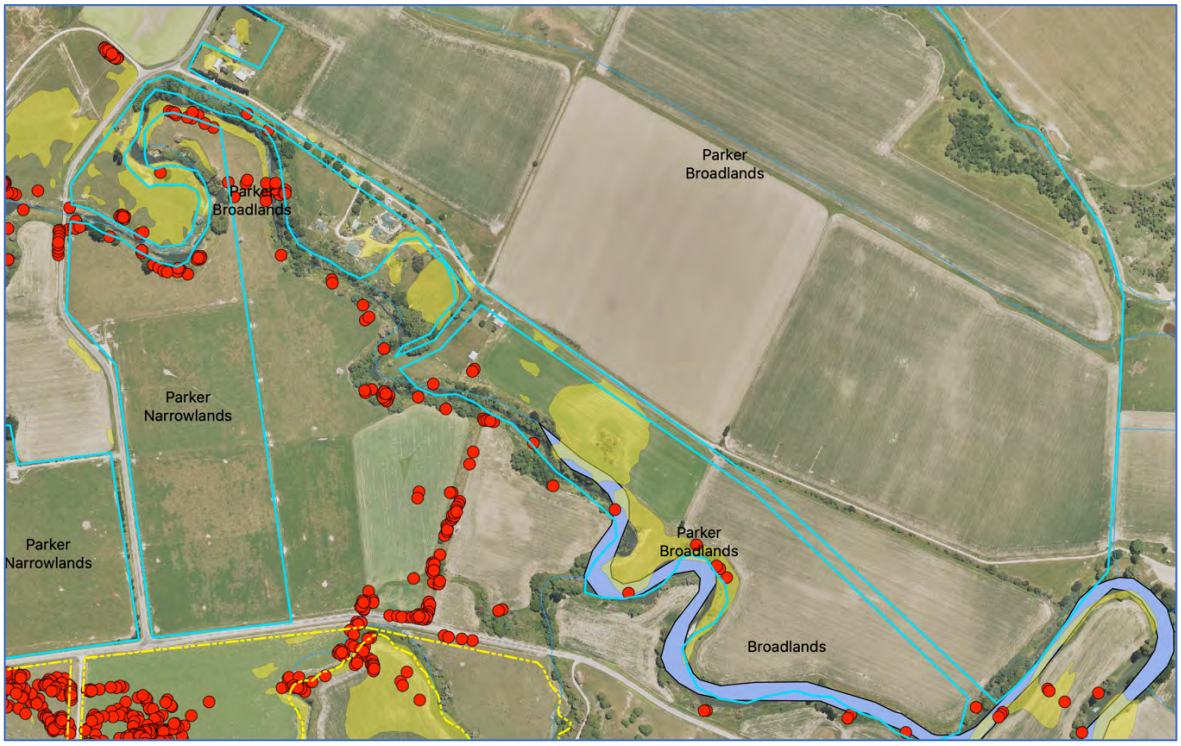

Figure Forty Three. *Parker Properties; Broadlands and Narrowlands (purchased after 2018) showing sediment deposition and distribution of woody debris from the Queens Birthday storm. Sediment deposition occurred at the Halley property which was significantly inundated (top left) while the Parker property experienced sediment deposition around the farmhouse and in two former meander bends east of the house. Some woody debris was also deposited but not to the extent that occurred on the true right bank particularly along the boundary fence at the Phillips property.*

Figure Forty Four. *Aerial view of the Paroa Road Bridge over the Mangaheia River (6th June 2018). There is no evidence of a log jam at the bridge. Sediment deposition at the left of the image suggests that this area is more low lying than at the bridge and thus there may have been a preferential path directing flood waters across the true left side of the flood plain.*

Figure Forty Five. *Maxar satellite (13th July 2018) showing the areas of significant sediment deposition and likely flow paths resulting from reduced flood conveyance capacity in the meander loop upstream.*

Lower Reaches.

Figure Forty Six. *Photograph (supplied) showing a fence damaged by slash and some larger woody debris on Broadlands.*

Figure Forty Seven. *Photograph (supplied) showing sediment deposition within a farm shed at Broadlands Farm.*

Lower Reaches

The area between the Broadlands Property and the point where the Mangaheia joins with the Uawa River is part of an extensive flood plain. The lowest 800m will have been influenced by flood flows from the Uawa itself, but above that point the Uawa would not have had a direct influence. None-the-less, sediment deposition and woody debris still affected this area (**Figure Forty Eight**).

For much of this stretch of river the sediment deposition is confined to the river banks but two low lying abandoned meander loops experienced what appears to be quite thick sediment deposits since the satellite imagery for the largest of these indicates that the logs that were deposited were almost completely covered by sediment. This means that the extent of woody debris deposition is not readily visible in the larger scale satellite imagery (**Figure Forty Nine**). When assessed in more detail, however, a large number of logs were identified in the outside bend above the largest area of sediment deposition (**Figure Forty Nine; inset**). This woody debris is visible in the aerial imagery obtained on the 6th of June 2018 (**Figure Fifty**).

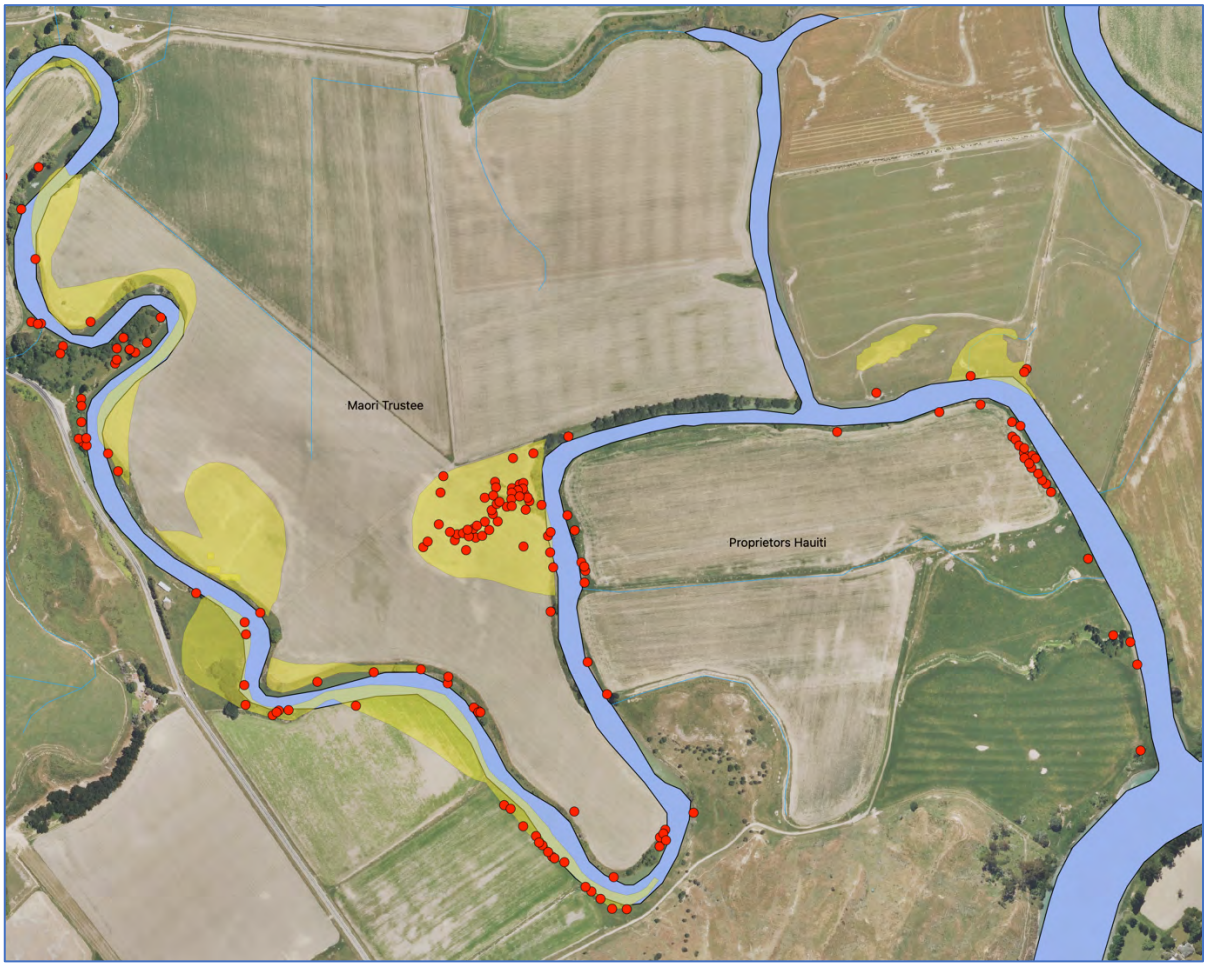

Figure Forty Eight. *Map of the area downstream of the Broadlands property showing the areas of sediment deposition and the distribution of woody debris. It is likely that the lower 800m was affected by flooding from the Uawa main stem but above that*

***Figure Forty Nine**. Maxar Satellite imagery of the lower reaches. Woody debris smothered by sediment is present in the abandoned meander loop (middle) and digger tracks through the deposited mud is visible leading from top left through to the abandoned meander loop. The inset (top right) shows detail for the meander loop bottom middle.*

***Figure Fifty**. Aerial imagery of the meander loop shown in **Figure Forty Nine (inset**). Woody debris is evident on the true right back (image far left).*

Analysis and Synthesis

Woody debris can be tracked from the Mangateao and Mangatoitoi streams in Uawa Forest to as far as the confluence of the Mangaheia with the Uawa River (*cf*. **Figure Four**). Given that logs and woody debris generally managed to traverse the entire river, it is highly likely that logs from Uawa forest also contributed to the material washed up at Tolaga Bay beach along with material from other forests. Pine, much of it having some degree of harvest processing (cut logs) dominated the woody debris within both the Mangaheia and wider catchment (*cf*. **Figure Three**) and on Tolaga Bay beach. There were contributions from other sources, particularly from the Arakihi tributary, but these were insignificant compared with the quantities that can be traced back to the Mangateao and Mangatoitoi streams.

The area covered by sediment downstream is significant with the sediment covering at least 223.5 Ha, however, much of the sediment will have remained in the river as both suspended and bedload sediment until it reached the sea at Tolaga. Low resolution sentinel satellite imagery dated 12th June 2018 shows that a significant sediment plume continued for some time (**Figure Fifty One**).

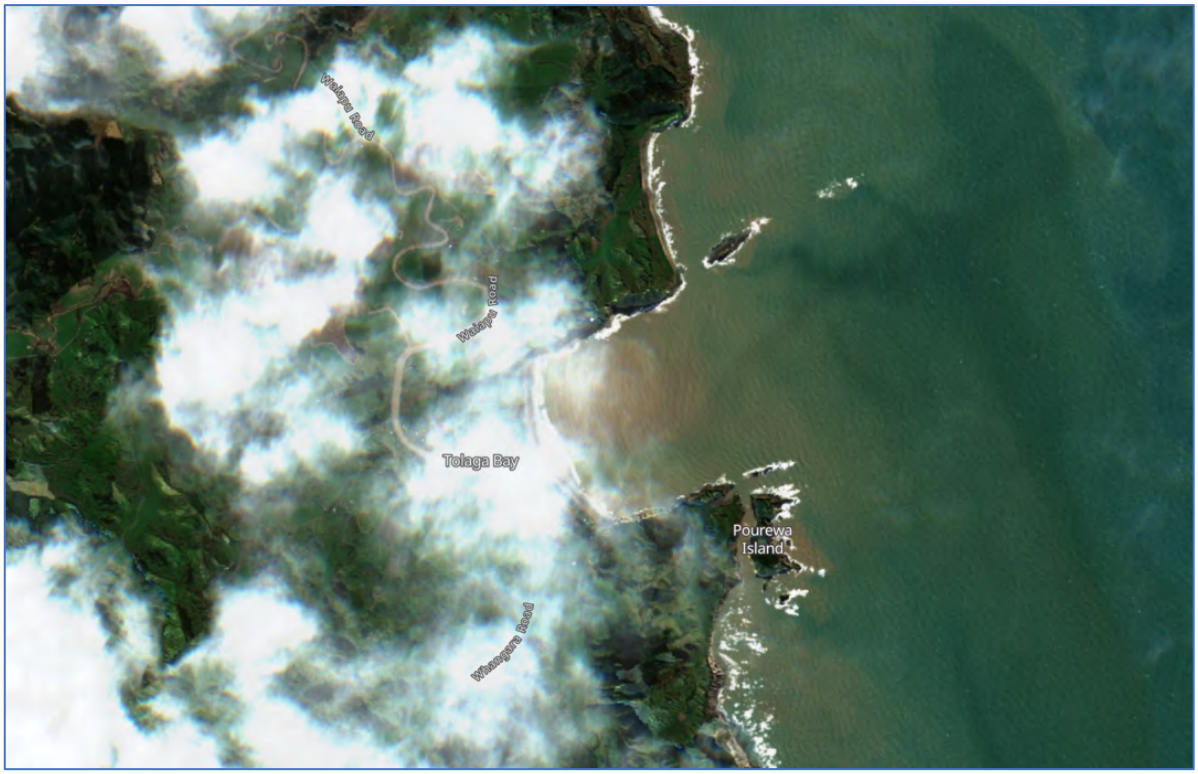

***Figure Fifty One**. Sentinel satellite imagery for the 12th June 2018 showing sediment discharge into Tolaga Bay.*

Damage to properties downstream of the Mangateao (*cf*. **Figures Five to Eight**) and Mangatoitoi (*cf*. **Figures Nine to Twelve**) streams was significant, with both sediment and woody debris deposited, pasture losses and damage to fences. Damage from deposition of sediment and woody debris was also significant for properties below Willowbank Forest and was widespread on Paki Tangohau's property (*cf*. **Figures Thirteen and Fourteen**).

Wigan Bridge acted as a debris dam (*cf*. **Figure Seventeen**) and this resulted in areas on Takapau road being inundated with sediment as a result of elevated water levels behind the

dam. The bridge was, however, an ineffective barrier and did not stop woody debris from reaching the lower catchment. The log jam raised water level upstream to the extent that debris-laden flood waters were able to bypass both the north and south abutments of the bridge (*cf*. **Figure Nineteen**). It is likely that additional temporary log jams occurred in the river both above and below Wigan bridge which resulted in elevated short term flood levels.

Large log jams also have an impact on bed sediment composition and biota via complex water flow-sediment-wood interactions. Log jams within rivers can strongly alter channel hydraulics and sediment transport, forcing a change in channel morphology. Thus the impact of woody debris on the river can be more than the obvious impact of damage to pastures and the need for removal. The woody debris can also directly cause river bank erosion exacerbating the loss of sediment from the river channel and accelerating meander channel migration potentially causing long term loss of productive land.

This can be seen downstream of Wigan bridge where debris laden flood waters inundated land on either bank discharging both sediment and woody debris. Woody debris lodged against trees on the riparian margin and against fences. This acts to deflect flows and causes localised backwater effects raising water levels in the vicinity (the process of afflux). The load of woody debris on fences can cause them to fail and broken fences were observed particularly on the true left bank of the Mangaheia between Wigan and Paroa Road bridges. Broken fences were also observed on Mangaheia Station on the south side of Tauwhareparae Road well away from the river (*cf*. **Figure Forty Two**).

In this stretch of river, ephemeral log jams in the active meander system is likely to have exacerbated overtopping directing water onto the low-lying flood plan. This is particularly evident on the Jefferd property upstream of the Warburtons, through the Warburtons citrus orchard and downstream paddocks, and on the Kerslake property where a maize crop was damaged. On the Kerslake property the breakout of debris-laden flood waters is clearly associated with a sharp meander bend (*cf*. **Figure Thirty Seven**). This was also the case immediately upstream of the Paroa Road bridge where sediment and woody debris-laden flood waters broke out in two stretches; one directing flow across the Simpson property and then onto Mangaheia Station and the other onto the Mangaheia 2D block and then onto the Broadlands/Parker property. Fencing and the bridge abutments on Paroa Road caught much of the woody debris and the Broadlands/Parker property and the Halley dwelling were mainly affected by sediment-laden flood waters.

Downstream of the Paroa Road bridge the volume of woody debris decreased largely because of the widening of the flood plain which would have reduced inundation depths and flow velocities. Sediment deposition still occurred but was more confined to areas close to the river as a result of reduced water velocities. Two low-lying former meandering bends on the Broadlands farm downstream of the Paroa road bridge were particularly affected (*cf*. **Figure Forty Five**).

Woody debris emanating from Uawa Forest was not the only impact and the large number of landslides within the forest resulted in a significant volume of sediment being discharged into the catchment. Sediment deposition is evident in both the aerial and satellite imagery acquired soon after the flood and is particularly evident in the photographs of both the Mitchell property (**Figure Thirty Five**) and the Parker property (**Figure Forty Seven**). Sediment deposition affected all of the downstream properties, however, not just those figured above.

Ecological effects

No assessments of ecological effects have been undertaken in the Mangaheia main stem itself. Reports were undertaken on the ecological affects in Mangatoitoi stream within the forest, in Kaitawa stream/estuary, and in the littoral zone at Tolaga Bay but these cannot be directly linked to the Mangaheia.

A longitudinal study into the long-term effects of sedimentation in the Mangaheia would be useful. While this study has looked at the effects of one event where one type of land use was the clear driver of the impacts, a longitudinal study would be able to examine all the drivers of sedimentation.

Uawa forest has now been replanted and the degree of vulnerability to landsliding should diminish over time. Phillips, *et. al* (1996), for example, cite a window of vulnerability of two to six years. An analysis of satellite imagery between 2019 and 2022 has demonstrated that the forest remains vulnerable 4 years later and some major landslides ranging from 1 to 3 Ha occurred within the forest within two years after the 2018 storm. It is anticipated that when this forest is next harvested in 25 years or so, mitigations within the forest as well as downstream will reduce the potential for impacts such as was seen in 2018.

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