# Analysis of Rainfall for the storm events of 11th-12th June. East Coast Tairawhiti

27 November 2018

Dr Murry Cave

## Summary

## Introduction

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 severe flooding in the Uawa and Pouawa catchments, the mobilisation of a large volume of sediment and woody debris from planation forests and necessitated the dramatic rescue of a family from the Mangatokerau River. This event is described in more detail in a separate report (Cave 2018a)

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. Overall, however, the impacts were felt more in the southern half of the region (Waiapoa and adjacent catchments) resulting in major floods and the mobilisation of a large volume of sediment and woody debris from planation forests, particularly from the headwaters of the Waimata. The second event also re-mobilise woody debris displaced from the forests during the Queens Birthday 1 event.

The economic, social and environmental impacts of both storms have been significant and recovery efforts are still continuing some four months later. The first storm resulted in around 47,000 $m^3$ of woody debris being deposited on the beach at Tolaga Bay and at least 500,000 $m^3$ of debris is estimated to be resident within the Uawa catchment in locations vulnerable to remobilisation in a storm event. At least 50,000 $m^3$ of woody debris is estimated to be resident within the Waimata catchment as a result of the second Queens Birthday storm.

## Objectives

The objectives of this study are to assess these two rainfall events to establish the following;

1. The duration and intensity of the rainfall events,
2. The distribution of the rainfall event,
3. Unpack the complexity of the rainfall event to aid understanding why it caused such significant impacts,
4. To understand the return period (or average recurrence interval) of the event, and finally,

5. To assess analytical methods and tools to better understand the potential of such storms to cause impacts within a reasonable forecast interval preceding the event.

## Data sources

Three separate data sets have been used in this analysis.

1. Rainfall gauges from the Gisborne District Council's (GDC) rain gauges network,
2. Uncalibrated rain gauge data provided by third parties, and
3. Met Service Rain Radar data calibrated by GDC rain gauge data.

## Data Quality

The GDC rain gauge data is collected at 10 minute intervals and is then aggregated to provided longer time interval datasets; ie, 1 hour, 12 hour and 24 hour accumulations. There are a number of issues despite the density of data generated.

Firstly, the rain gauge distribution is not perfect with some gauges being located close to each other while in other areas there are large spatial gaps. Secondly, one or more gauges may not have provided accurate readings; for example the Oates Street urban gauge recorded a zero value with other gauges close by recorded meaningful data.

Secondly, the standard of rainfall data reported by the third party gauges is unknown and such data needs to be treated with caution and as such has been omitted from this analysis. Also while there is probably more third party rainfall data available, Council was unable to get these records.

Thirdly, the Met Service rain radar data was supplied as low resolution raster files with no embedded spatial metadata meaning that it could not be directly loaded into a GIS to allow for spatial analysis. Associated digital data, while containing metadata could not be spatially analysed as the attributes required propriety software to allow for it to be analysed. The raster data was manually geocoded (rubber sheeted) to convert it to a form that could be used in a GIS. This process could have produced potential errors but these have not been tested.

## Severe Weather warnings

Unlike for the Queens Birthday storm of 3$^{rd}$-4$^{th}$ June, the MetService weather warnings for the Storm that occurred on the 11$^{th}$-12$^{th}$ June 2018 more accurately reflected the severity of the storm that eventuated. The severe weather warnings received are shown in **Figure One**.

### Severe Weather Warnings for Gisborne

Issued 10:45am Sunday 10 Jun 2018

**Situation**

HEAVY RAIN FOR WESTLAND UNTIL THIS (SUNDAY) EVENING. HEAVY RAIN FOR GISBORNE AND HAWKES BAY DURING MONDAY AND TUESDAY. A front lies slow-moving over Westland and is forecast to weaken this (Sunday) afternoon. Heavy rain is expected to continue between Bruce Bay and Otira until early this evening and a Warning remains in force for this area. A deepening sub-tropical low is forecast to move onto the North Island from the north during Monday and then slowly move off to the southeast of the country during late Tuesday or on Wednesday. There is significant uncertainty regarding the intensity and position of this low as it moves across the North Island, therefore, please stay up to date with the latest forecasts and warnings. At this stage the heaviest rain is expected in Gisborne and Hawkes Bay during Monday and Tuesday and a Warning is in force for these areas.

**Heavy Rain Warning for Gisborne**

Issued 10:43am Sunday 10 Jun 2018

Area: Gisborne. Valid: 23 hours from 3:00 pm Monday to 2:00 pm Tuesday. Periods of heavy rain expected from Monday afternoon to Tuesday afternoon. During this time expect 120 to 200mm to accumulate, especially about the ranges. Peak intensities 15 to 25mm per hour, and thunderstorms are possible on Tuesday.

### Severe Weather Warnings for Gisborne

Issued 08:02pm Sunday 10 Jun 2018

**Situation**

HEAVY RAIN FOR GISBORNE AND HAWKES BAY DURING MONDAY AND TUESDAY, AND SEVERE SOUTHEAST GALES FOR EASTERN BAY OF PLENTY. A deepening subtropical low is moving south toward the North Island. This low is forecast to move forecast to move onto the North Island during Monday and Tuesday accompanied by heavy rain and easterly gales, and then slowly move away to the southeast on Wednesday. At this stage the heaviest rain is expected in Gisborne and Hawkes Bay during Monday and Tuesday, and a Warning is in force for these areas. This Warning now also covers severe east to southeast gales for eastern Bay of Plenty. Please note, that the rain is easing in Westland, and the warning has been lifted.

**Heavy Rain Warning for Gisborne**

Issued 08:00pm Sunday 10 Jun 2018

Area: Gisborne. Valid: 24 hours from 3:00 pm Monday to 3:00 pm Tuesday. Expect 150 to 220mm to accumulate, especially about the ranges. Peak intensities 15 to 25mm per hour, especially in possible thunderstorms on Tuesday.

### Severe Weather Warnings for Gisborne

Issued 10:47am Monday 11 Jun 2018

**Situation**

HEAVY RAIN AND SEVERE GALES FOR PARTS OF NORTHERN AND CENTRAL NEW ZEALAND Watch for strong winds in Taranaki upgraded to a Warning in this update. A deepening sub-tropical low is moving southwards toward the North Island, and is expected to move onto the Bay of Plenty during Tuesday morning and lie near Taranaki by midnight Tuesday. The low will bring heavy rain and gales to many parts of northern and central New Zealand.

**Heavy Rain Warning for Gisborne**

Issued 10:45am Monday 11 Jun 2018

Area: Gisborne. Valid: 24 hours from 2:00 pm Monday to 2:00 pm Tuesday. Expect 150 to 220mm to accumulate, especially about the ranges. Peak intensities 15 to 25mm per hour, especially in possible thunderstorms on Tuesday.

### Severe Weather Warnings for Gisborne

Issued 09:17pm Monday 11 Jun 2018

**Situation**

HEAVY RAIN AND SEVERE GALES FOR PARTS OF NORTHERN AND CENTRAL NEW ZEALAND Please Note: Watch for heavy rain in Coromandel Peninsula, Bay of Plenty including Rotorua and the Kaimai Range, also the Tararua Range is now upgraded to a Warning. Also, Watch for strong winds in the Marlborough Sounds is now upgraded to a Warning. A deepening sub-tropical low is moving south towards the North Island, and is expected to move onto the Bay of Plenty during Tuesday morning and lie near the central high country by midnight Tuesday, then move southeastwards and lie just to the southeast of central New Zealand by midday Wednesday. The low will bring heavy rain and gales to many parts of northern and central New Zealand.

**Heavy Rain Warning for Gisborne**

Issued 09:15pm Monday 11 Jun 2018

Area: Gisborne. Valid: 19 hours from 9:00 pm Monday to 4:00 pm Tuesday. Expect 150 to 220mm to accumulate on top of what has already fallen, mainly about the ranges. Peak intensities 15 to 25mm per hour. Thunderstorms also possble.

**Heavy Rain Warning for Bay Of Plenty**

Issued 09:15pm Monday 11 Jun 2018

Area: Bay Of Plenty including Rotorua and the Kaimai Range. Valid: 21 hours from 3:00 am Tuesday to 12:00 am Wednesday. Expect 110 to 150mm of rain to accumulate. Peak intensities 15 to 25mm per hour.

### Severe Weather Warnings for Gisborne

Issued 09:44am Tuesday 12 Jun 2018

**Situation**

HEAVY RAIN AND SEVERE GALES FOR PARTS OF NORTHERN AND CENTRAL NEW ZEALAND Please Note: Tongariro National Park, Wairarapa and eastern hills of Wellington have been upgraded to a warning for heavy rain. A deep sub-tropical low near Bay of Plenty is expected to move south to lie near the central high country by midnight Tuesday, then move southeast and lie just southeast of central New Zealand by midnight Wednesday. The low will bring heavy rain and gales to many parts of northern and central New Zealand.

**Heavy Rain Warning for Gisborne**

Issued 09:42am Tuesday 12 Jun 2018

Area: Gisborne. Valid: 7 hours from 9:00 am to 4:00 pm Tuesday. Expect a further 50 to 70mm to accumulate on top of what has already fallen, mainly about the ranges. Peak intensities 10 to 15mm per hour.

**Heavy Rain Warning for Bay Of Plenty**

Issued 09:42am Tuesday 12 Jun 2018

Area: Bay Of Plenty including Rotorua and the Kaimai Range. Valid: 15 hours from 9:00 am Tuesday to 12:00 am Wednesday. Expect 110 to 150mm of rain to accumulate. Peak intensities 15 to 25mm per hour.

*Figure One. Severe Weather warnings and watches 11th -12th June storm.*

## *Situation*

The 11th-12th June 2018 storm appears to be a more typical storm than the Queens Birthday storm. The MetService synoptic map for the 11th of June suggests that a sub tropical low situated to the north of Bay of Plenty-East Cape would move south over the intervening 24 hours (**Figure Two**). A severe weather outlook issued on the 10th of June indicated that heavy rain was predicted with a high level of confidence for all of Tairawhiti (**Figure Three**).

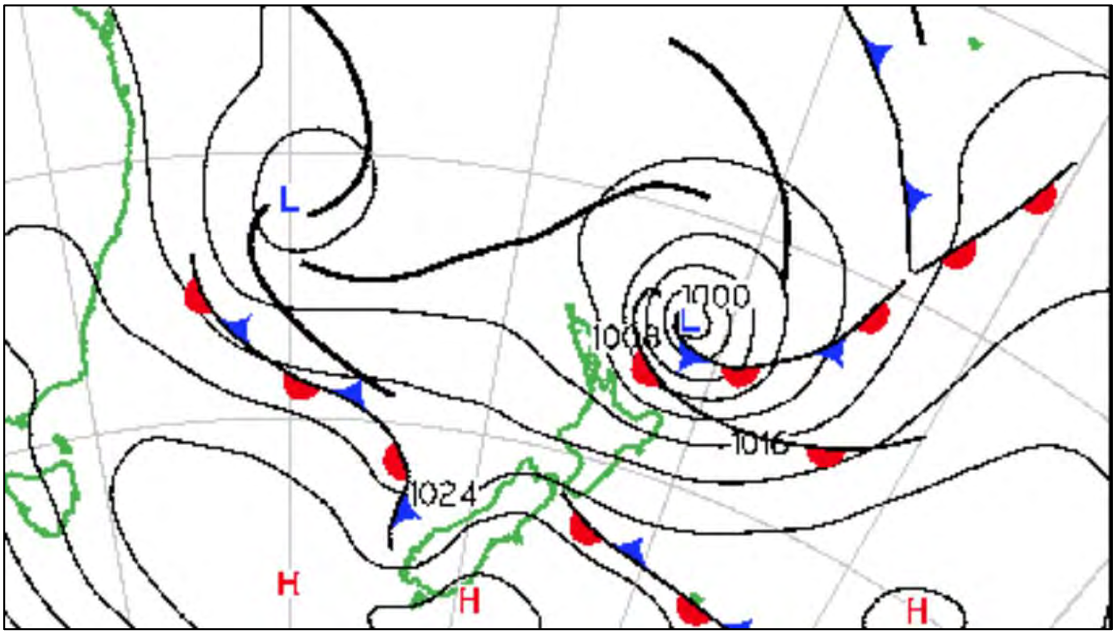


***Figure Two.*** *Synoptic map for the 11th -12th June storm showing a low moving south approaching East Cape on the 11th.*

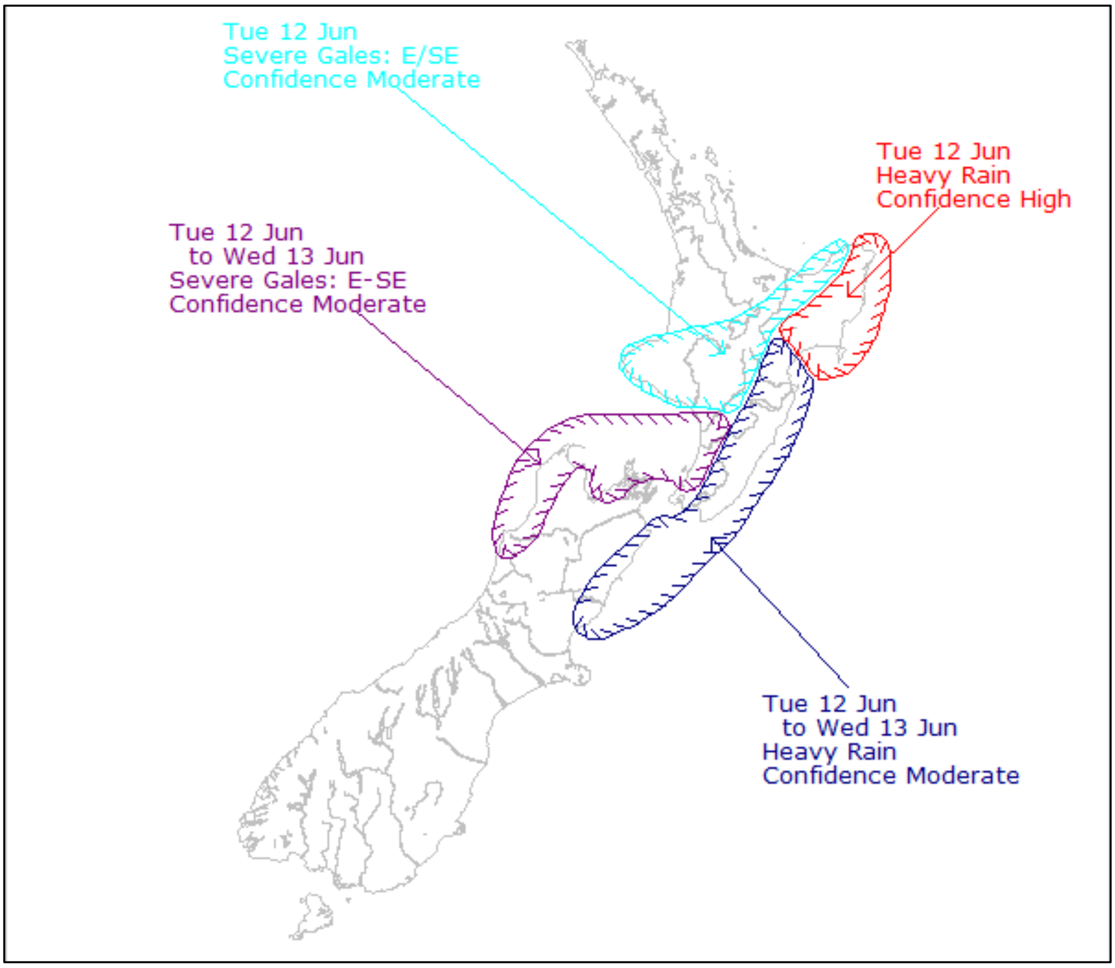


***Figure Three.*** *MetService outlook map dated 2:14pm 10th June 2018 which showed heavy rain with a high level of confidence for the region.*

## Rainfall Data

This analysis of rainfall data for the East Coast Tairawhiti Region is based on 59 rain gauges distributed across the area from Hicks Bay in the north to the top of the Wharerata in the south. There is a gap in coverage in the west while coverage to the north may be too coarse to adequately define rainfall distribution across the area (**Figure Four**). Raw rainfall data is presented as **Appendix One**.


***Figure Four.*** *Location of rain gauges within East Coast/Tairawhiti.*

When the aggregated rain gauge data is plotted which suggests a simple bell curve with the storm initiation around 1pm on the 11th June and ending by midday on the 12th June (**Figure Five**). There are a couple of minor peaks before and particularly after the main event but these do not seem significant (see **Figure Five**).

Overall, it suggests that the event can be classed as a 24 hour event unlike the Queens Birthday storm that had a peak duration of around 6 to 8 hours. The duration of the event appears to be the critical driver of the flooding that occurred in the Waipaoa.

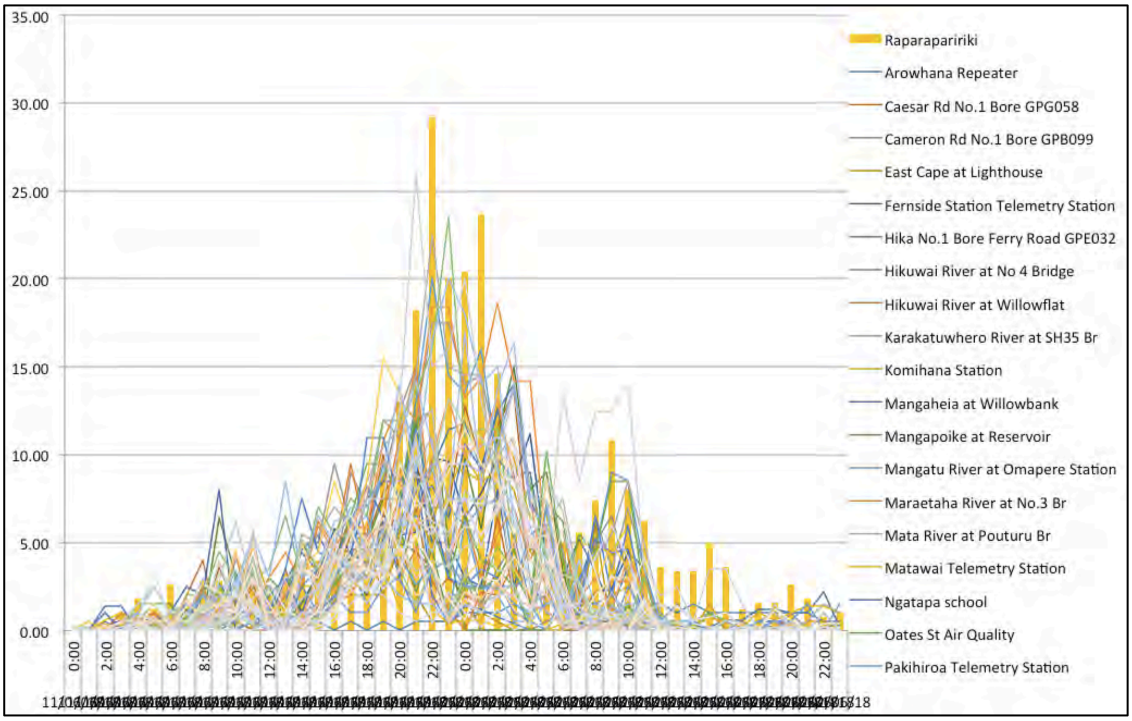


***Figure Five.*** *Aggregate of all rain gauges for the storm of 11th and 12th June 2018 which generally suggests a simple bell curve rainfall distribution over time with a minor peak (8mm/hr) prior to the main event and a 10 to 14mm peak soon after the main event.*

Because much of the detail is lost in **Figure Five**, the hourly maximum rainfall was calculated for each hour. This plot does not suggest a picture of the storm that is much different from the aggregated data although it indicates that the precursor and post main storm tails would have contributed to the event (**Figure Six**).

When it is further unpacked by plotting 4 key sensitive gauges over the duration of the storm, it indicates that peak rainfall accumulations occurred at two rain gauge sites, Raparapariiki (RIP) and Waikura (**Figure Seven**).

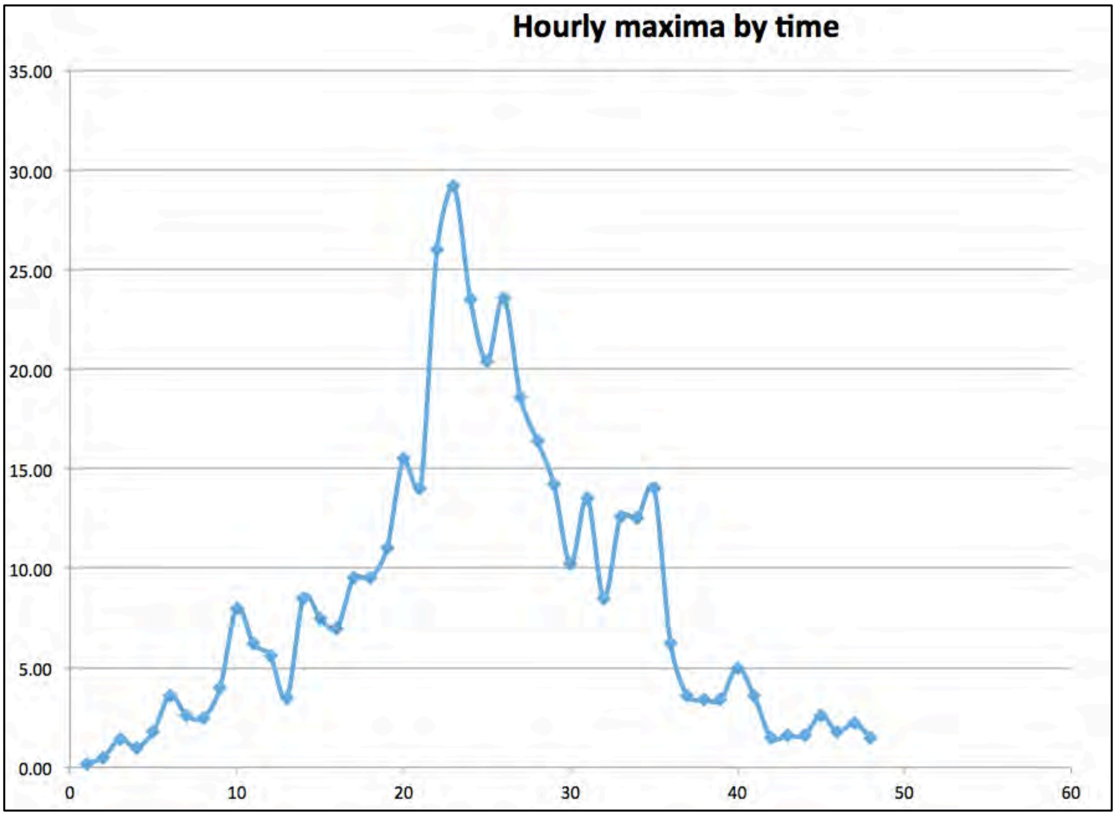


***Figure Six.*** *Hourly maxima rainfall accumulations for the 11$^{th}$-12$^{th}$ June 2018 event. This suggests a fairly simple storm profile. While the main storm event is around 24 hours long there were significant tails resulting in a total rainfall accumulation covering around 30 hours.*

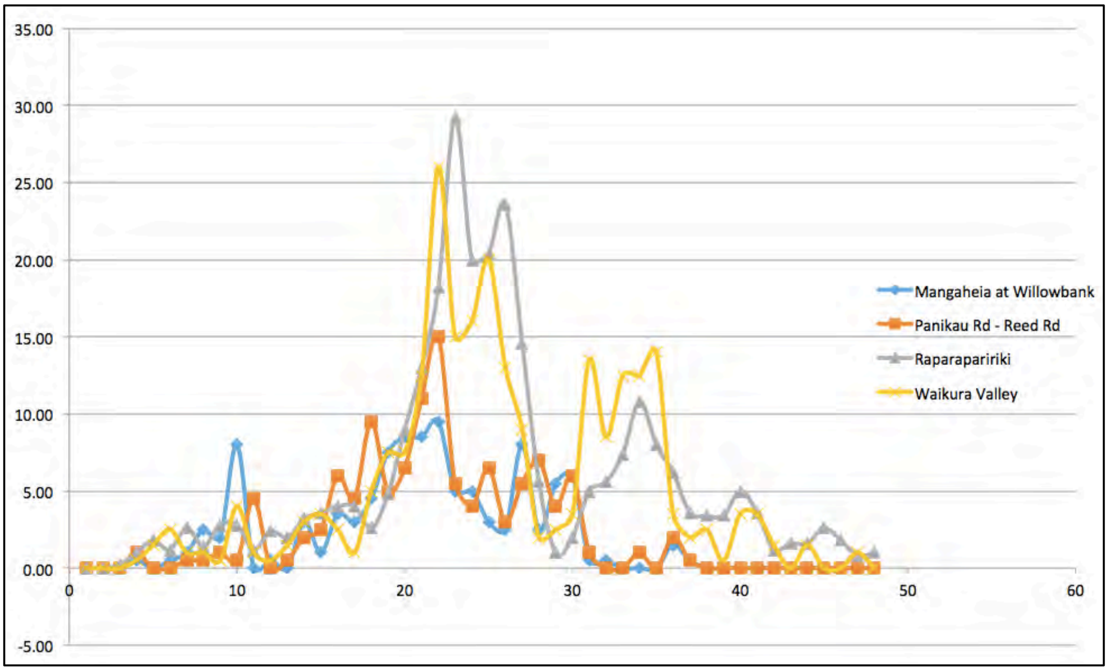


***Figure Seven.*** *Plot of the hourly rainfall accumulations for the two heaviest rainfall gauges (Raparapariki-RIP) and Waikura Valley compared with Panikau-Reed Road and Mangaheia at Willowbank. The Panikau-Reed Road gauge had a short peak of 15mm in one hour while the Mangaheia gauge did not go above 10mm.*

This raises a key point, however, since Raparapaririki (RIP) [Waiapu catchment] and Waikura [Wharekahika catchment] both occur in the northern half of the Tairawhiti region (see **Figure Four**) while the most widely reported flooding occurred in the Waipaoa catchment in the southern half on Tairawhiti (see section below).

In fact, a significant flood event did occur in the Waiapu Catchment and it resulted in a significant woody debris mobilisation event. Unlike further south, however, the debris comprised a complex mix of debris (**See page xx below**)

*Waipaoa Rainfall accumulation*

Because the focus of this investigation has been on the southern catchments, the rain gauges for the Waipaoa catchment (**Figure Eight**) have been examined in detail (**Figure Nine**).

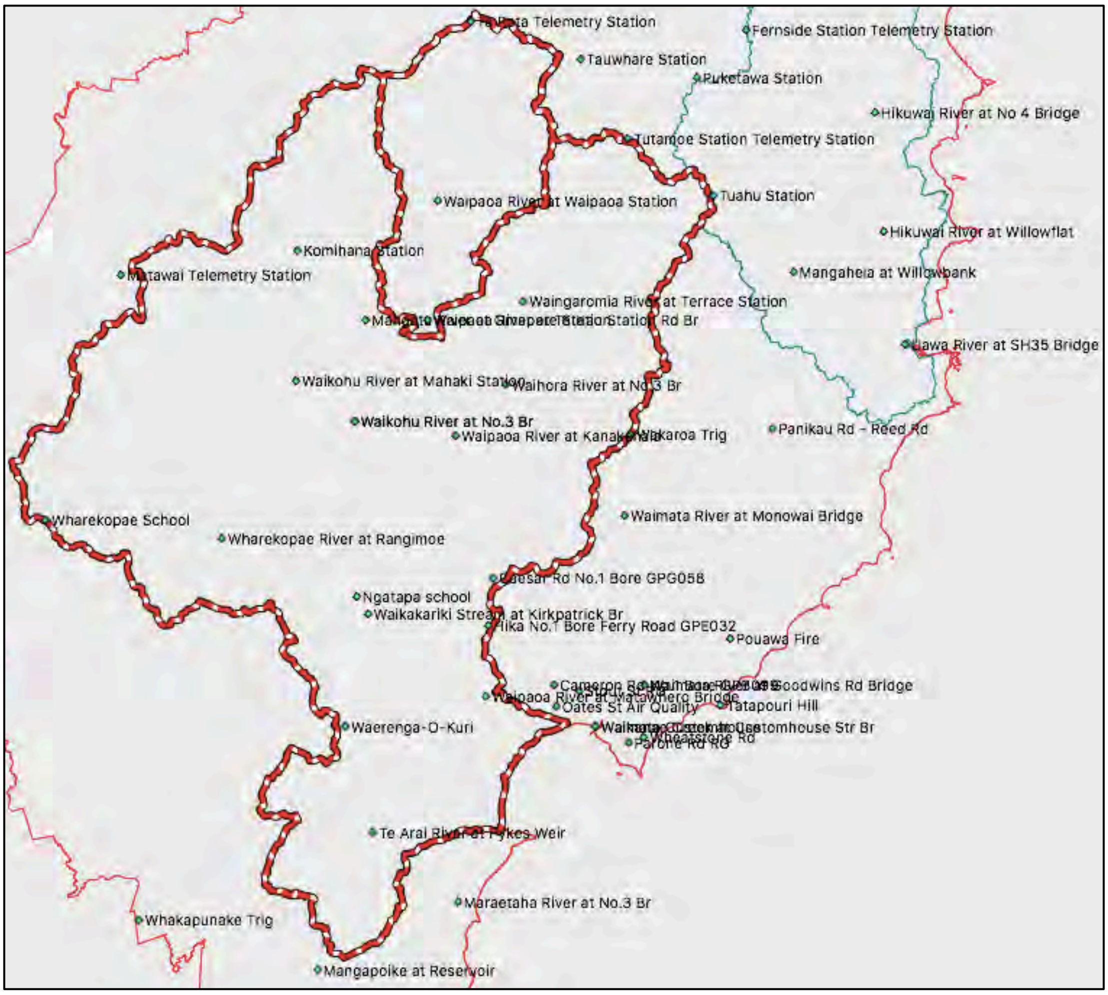


***Figure Eight.*** *Map showing the location of rain gauges in the Waipaoa Catchment*

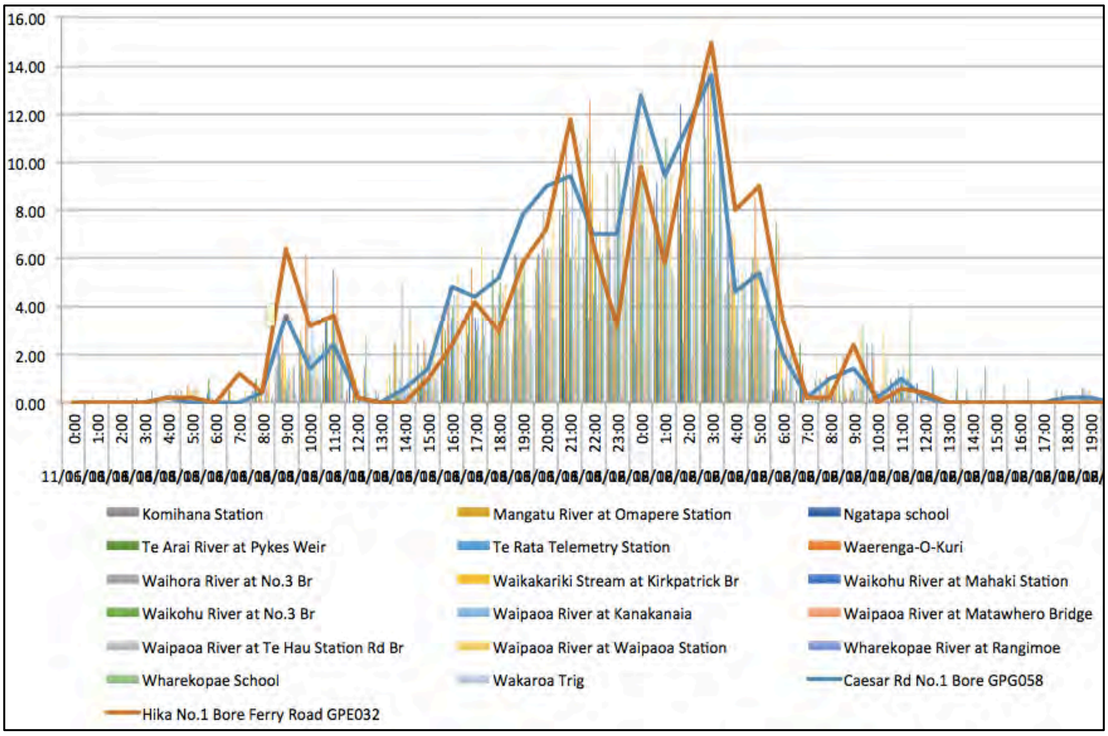


***Figure Nine.*** *Plot of all Waiapoa catchment rain gauge accumulations with the Hika No.1 Bore Ferry Road gauge shown as an orange line plot and the Caesar Road gauge in blue.*

These gauge sites suggest that the hourly rainfall accumulations within the Waipaoa catchment were only moderate. Peak hourly rainfalls were around 12mm per hour generally but with several sites, particularly Hika No 1 bore on Ferry Road, reaching 15mm per hour over a short period. Other sites in the plus 12mm hourly peaks were Caesar Road, and Wairenga O Kura.

Both Hika and Caesar Road are on the eastern side of the catchment and suggested that elevated rainfall accumulation may have been from the east. Hence the hourly maxima for the Waipaoa gauges have been compared with adjacent gauges from the Waimata, Pouawa, Pakarae Uawa and Waiapu catchments (**Figure Ten**).

This indicates that, indeed, rainfall accumulations were higher in the bordering catchments in the north and east with Tuahu Station having a maxima of just under 25mm while Tutamoe, Tauwhare, and Puketawa Stations, and Waimata at Monowai all had peak hourly accumulations approaching 20mm (**Figure Eleven**). The 1 hour, 12 hour and 24 hour rain gauge accumulations for all gauges are shown in **Table One**.

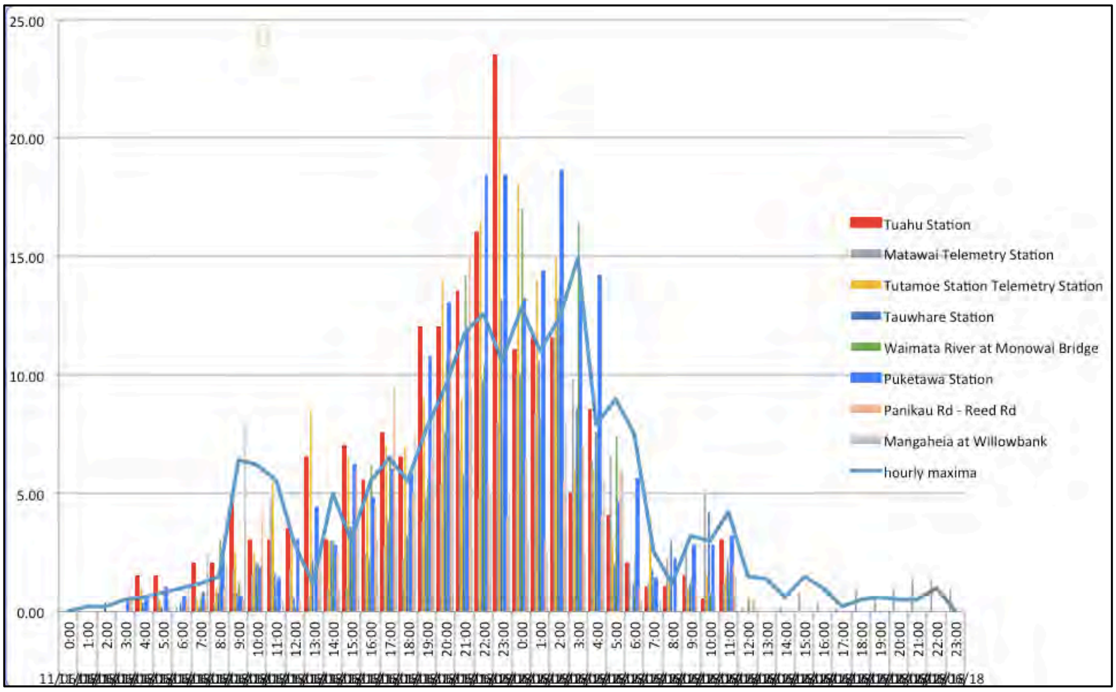


***Figure Ten.*** *Plot of all Waipaoa catchment rain gauge accumulations plotted as an aggregated hourly maxima compared with bordering gauges in adjacent catchments.*

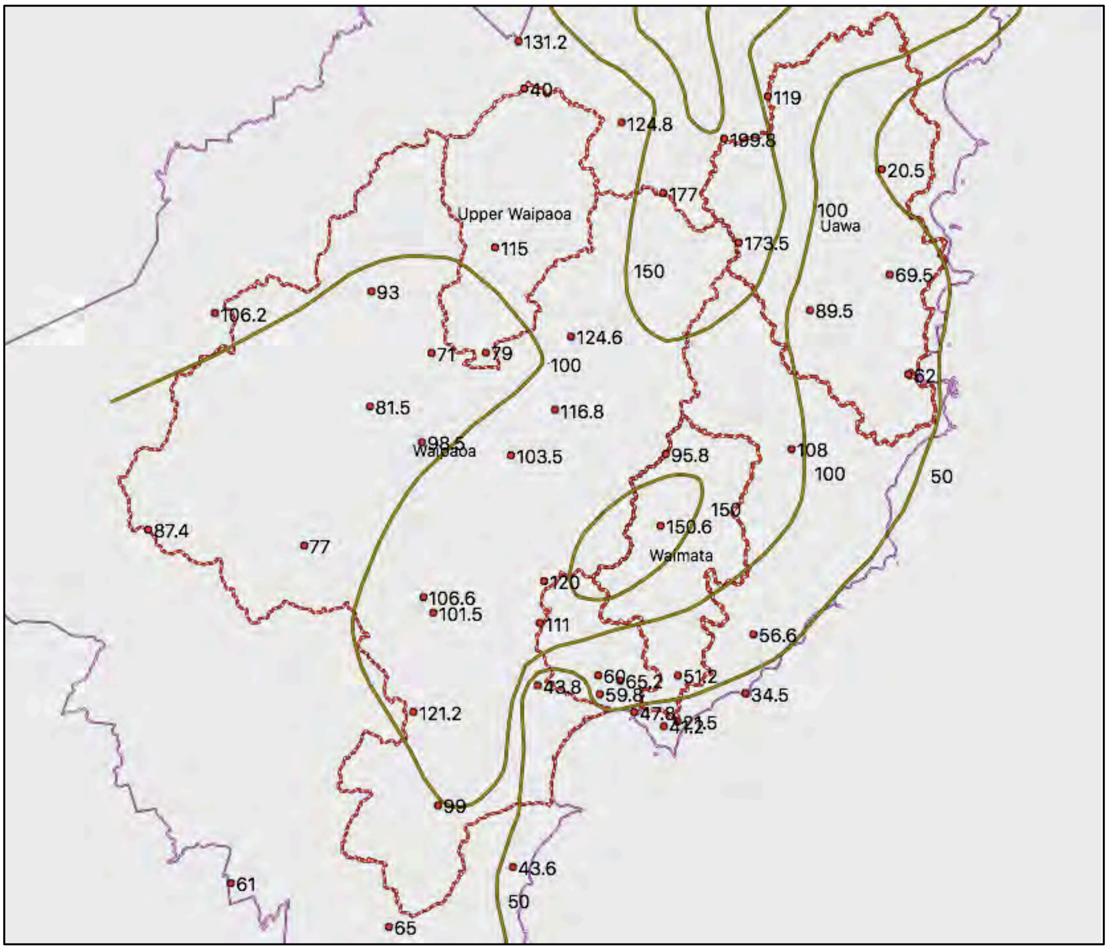


***Figure Eleven.*** *Rainfall isopleth of southern Tairawhiti showing the Waiapoa, Waimata, and Uawa Catchments.*

*Waiapu rainfall accumulation*

As noted above, the northern catchments received considerably more rainfall than in the south with the Waiapu and Wharekahika catchments experiencing heavy rain (see **Figure Seven above and Figure Eleven below**). The Raparapaririki (RIP) rain gauge in the headwaters of the Waiapu Catchment had the highest rainfall accumulation with 225.4mm of rain falling over the 24 hours of the storm. The Waikura rain gauge had a 24 hour accumulation of 216mm (**Table One**).

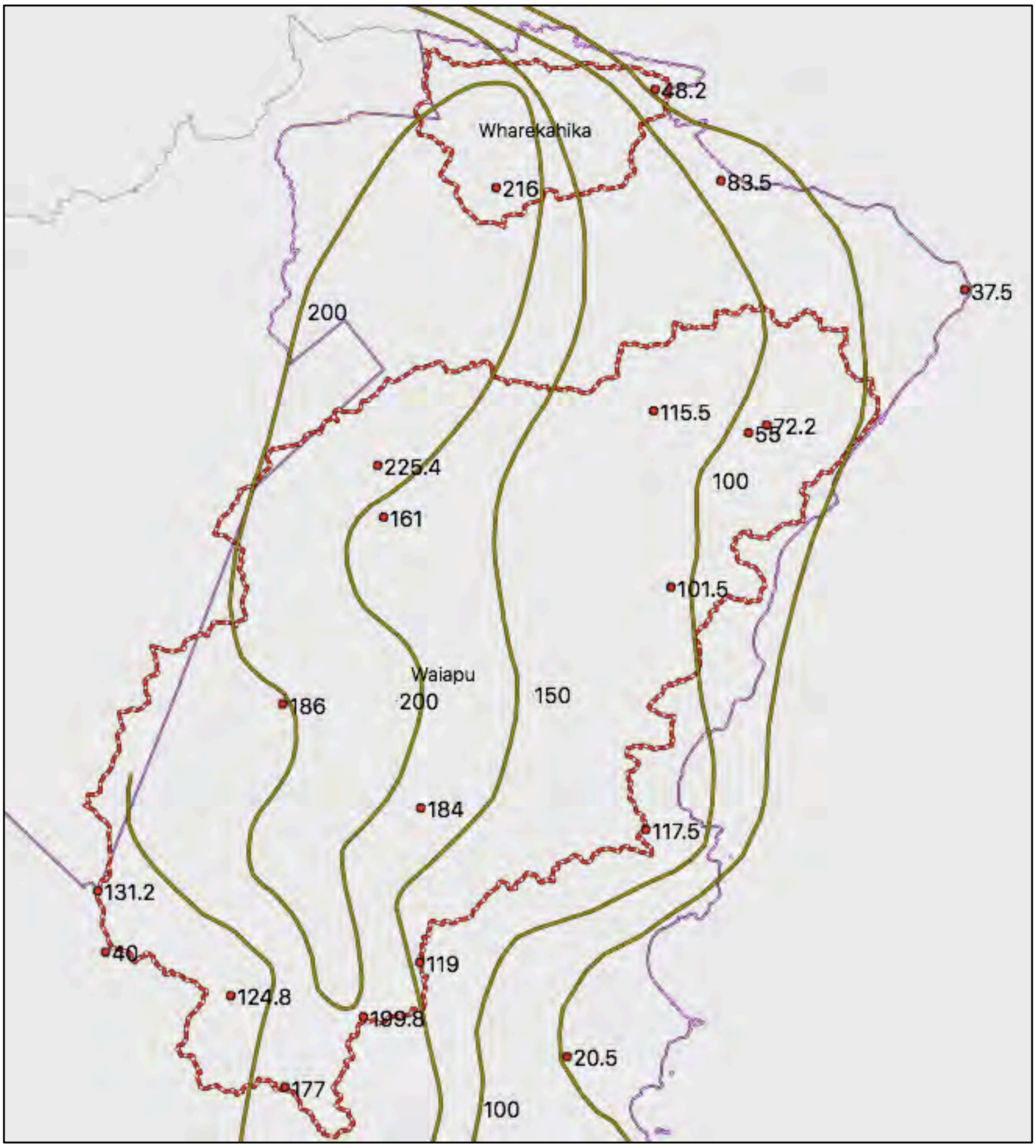


***Figure Eleven.*** *Rainfall isopleth of northern Tairawhiti showing the Waiapu and Wharekahika Catchments [Note that heavy rain also accumulated in the Waikura and Whangaparaoa Catchments which discharge west into the Bay of Plenty].*

| Station | 24 hour | 12 hour | 1 hour (mx) |
|---|---|---|---|
| Arowhana Repeater | 131.2 | 96.8 | 12.6 |
| Caesar Rd No.1 Bore GPG058 | 120 | 99.6 | 13.6 |
| Cameron Rd No.1 Bore GPB099 | 60 | 47 | 8.5 |
| East Cape at Lighthouse | 37.5 | 12 | 6 |
| Fernside Station Telemetry Station | 119 | 85.4 | 11.2 |
| Hika No.1 Bore Ferry Road GPE032 | 111 | 96.5 | 15 |
| Hikuwai River at No 4 Bridge | 20.5 | 10.5 | 2 |
| Hikuwai River at Willowflat | 69.5 | 45 | 10 |
| Karakatuwhero River at SH35 Br | 83.5 | 43 | 15 |
| Komihana Station | 93 | 74 | 9.5 |
| Mangaheia at Willowbank | 89.5 | 64.5 | 9.5 |
| Mangapoike at Reservoir | 65 | 44.5 | 12.5 |
| Mangatu River at Omapere Station | 71 | 57.5 | 7.5 |
| Maraetaha River at No.3 Br | 43.6 | 33.4 | 6.2 |
| Mata River at Pouturu Br | 184 | 127.5 | 17.5 |
| Matawai Telemetry Station | 106.2 | 83.6 | 11.6 |
| Ngatapa school | 106.6 | 96 | 14 |
| Oates St Air Quality | 59.8 | 44.8 | 7.2 |
| Pakihiroa Telemetry Station | 161 | 110.5 | 20 |
| Panikau Rd - Reed Rd | 108 | 75 | 15 |
| Parone Rd RG | 41.2 | 28.8 | 5 |
| Poroporo Fire | 55 | 13.2 | 6.2 |
| Poroporo River at SH35 Bridge | 72.2 | 24.8 | 9.2 |
| Poroporo Telemetry Station | 115.5 | 56.5 | 12.5 |
| Pouawa Fire | 56.6 | 37.4 | 7 |
| Puketawa Station | 199.8 | 157.4 | 18.6 |
| Puketoro Telemetry Station | 186 | 125.5 | 22.5 |
| Raparapaririki | 225.4 | 161.6 | 29.2 |
| Ruatoria Telemetry Stn at Barry Ave | 101.5 | 50 | 11.5 |
| Stout St RG | 65.2 | 49.2 | 10.2 |
| Tatapouri Hill | 34.5 | 17.5 | 6.5 |
| Tauwhare Station | 124.8 | 94.4 | 13.2 |
| Te Arai River at Pykes Weir | 99 | 82 | 11 |
| Te Puia | 117.5 | 72 | 15.5 |
| Te Rata Telemetry Station | 40 | 28.5 | 4 |
| Tuahu Station | 173.5 | 130.5 | 23.5 |
| Tutamoe Station Telemetry Station | 177 | 130.5 | 20 |
| Uawa River at SH35 Bridge | 62 | 36.8 | 9.6 |
| Waerenga-O-Kuri | 121.2 | 99.4 | 13.8 |
| Waihora River at No.3 Br | 116.8 | 93.6 | 12.2 |
| Waikakariki Stream at Kirkpatrick Br | 101.5 | 91.5 | 14 |
| Waikanae Creek at Customhouse St Br | 47.8 | 34.6 | 5.6 |
| Waikohu River at Mahaki Station | 81.5 | 66.5 | 8.5 |
| Waikohu River at No.3 Br | 98.5 | 83.5 | 11 |
| Waikura Valley | 216 | 140.5 | 26 |
| Waimata River at Goodwins Rd Bridge | 51.5 | 35 | 8.6 |
| Waimata River at Monowai Bridge | 150.6 | 121 | 17 |
| Waingaromia River at Terrace Station | 124.6 | 96 | 13.2 |
| Waipaoa River at Kanakanaia | 103.5 | 87 | 11 |
| Waipaoa River at Matawhero Bridge | 43.8 | 33.2 | 5.2 |
| Waipaoa River at Te Hau Station Rd Br | 79 | 61.2 | 7.4 |
| Waipaoa River at Waipaoa Station | 115 | 80.5 | 11.5 |
| Wakaroa Trig | 95.8 | 73.4 | 10.8 |
| Whakapunake Trig | 61 | 46.4 | 5 |
| Wharekahika River at Hicks Bay Rd Br | 48.2 | 23.6 | 7.6 |
| Wharekopae River at Rangimoe | 77 | 64.5 | 11 |
| Wharekopae School | 87.4 | 65.4 | 9.4 |
| Wharerata at Radio Track Rd | 69.4 | 44.2 | 7 |
| Wheatstone Rd | 21.5 | 17 | 2.5 |

***Table One.*** *Rain Gauge data for the storm of 11th-12th June 2018 showing the 24 hour (starting at 1pm on the 11th), 12 hour (starting at 7pm on the 11th), and 1 hour (maximum hourly rainfall per gauge falling within the 24 hour accumulation). See Appendix One and Two for raw data.*

This resulted in significant flooding with the Waiapu spreading across the flood plain in its lower reaches. A significant amount of woody debris was deposited on the flood plain east of Ruatoria and on the Tikapa beach south of the Waiapu River mouth.

The character of the woody debris differs significantly from that observed in the south of the region with pine comprising 40%, willow/poplar 11%, indigenous 19%, fence battens and posts 5%, and small broken material making up the final 25%. Much of the pine and willow/poplar was weathered and unlike in the south there was less obvious cut pine, and more long resident logs and root ball material.

A scan of good quality post-event (25$^{th}$ August) satellite imagery and 2$^{nd}$ July 10m resolution Sentinel imagery identified some areas of localised landslides. These weren't significant, however, and closed canopy forests appeared largely intact.

An inspection of forestry at the top of the Mata Road found some signs of landsliding and material had been mobilised from river level landings at the Whakeao. It is considered that much of the pine was material already in vulnerable locations in the catchment following Cyclone Cook in 2017.

Cave (*et al*) 2017 noted that a significant mobilisation of material had occurred in the Mata sub-catchment of the Waiapu as evidenced by the destruction of a large slash catcher and mobilisation of harvest waste stored on the flood plain at Whakaeo. Much of this material was not located, however, with it being inferred as being distributed within hard-to-access locations within the catchment.

**Rain Radar**

The Met Service provided rain radar for the 11-12$^{th}$ June but overall these proved less useful than the imagery provided for the 3$^{rd}$ – 4$^{th}$ June event. The first image shows the storm sweeping across the northern Raukumara Ranges as a broad band. This is consistent with the rain gauge data showing that the storm was more intense in the north.

Also evident on this image are the bright (red) cells located in the vicinity of the Raparapaririki (RIP) rain gauge (**Figure Twelve**). A narrow band also extends to the south at the headwaters of the Waipaoa while a second narrow band across the Wharerata. The majority of the Uawa Catchment appears largely clear of significant rain.

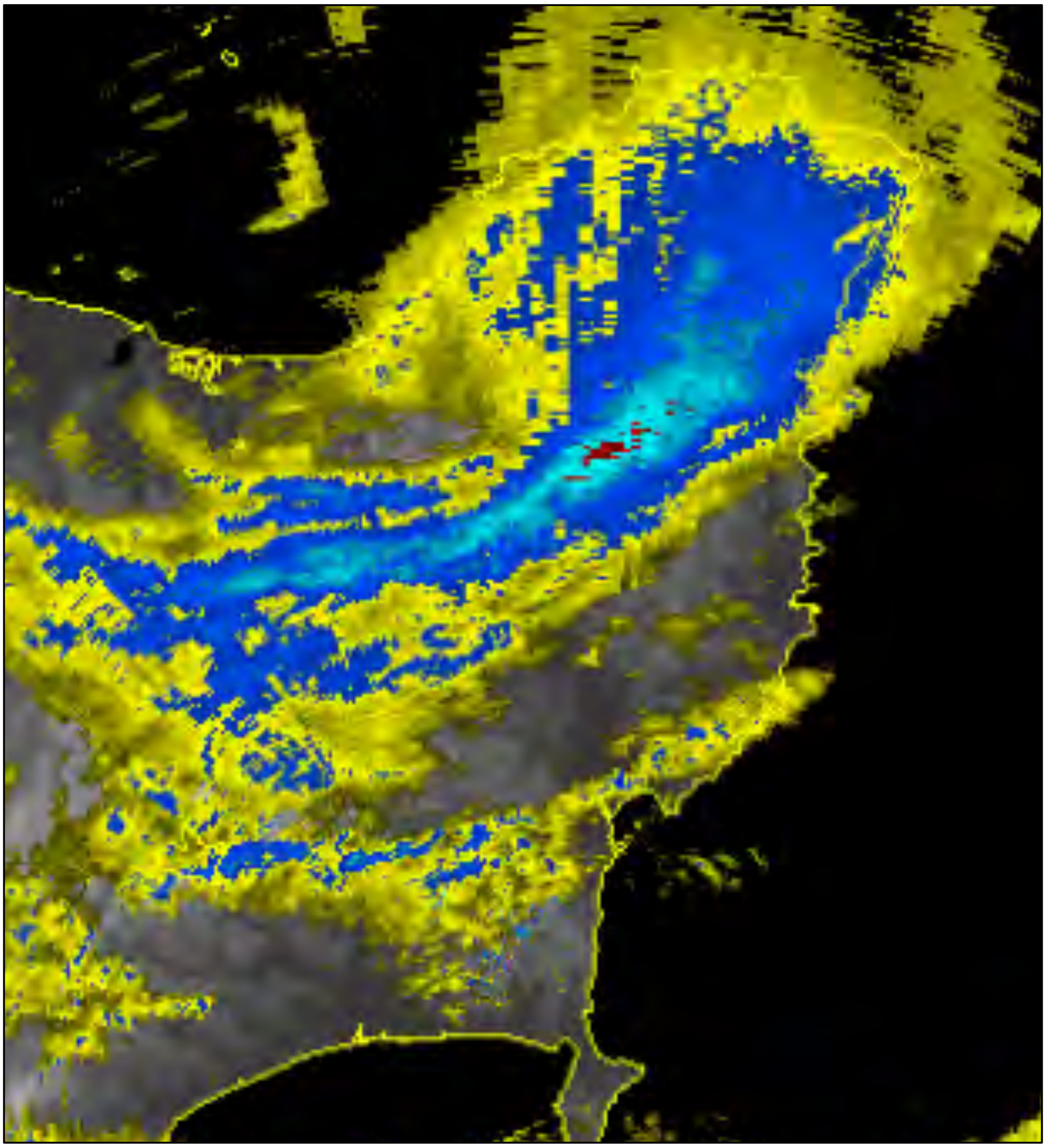

***Figure Twelve.*** *Rain radar image showing the storm sweeping south east across the Raukumara Ranges with the bright spots associated with intense rain in the head of the Waiapu. A narrower band of heavy rain is event in the headwaters of the Waipaoa and adjacent catchments.*

A second image dated at 00.00 hours on the 12th UTC time (midday 12th NZ time) shows the 24 hour accumulation for the entire storm (**Figure Thirteen**). This that a band of relatively heavy rain covered the entire region north of Te Karaka and particularly over the Wharerata where pixel densities suggest rainfall accumulations of between 150 and 200mm over 24 hours. This image does not extend into the Waiapu and has not been geo-corrected.

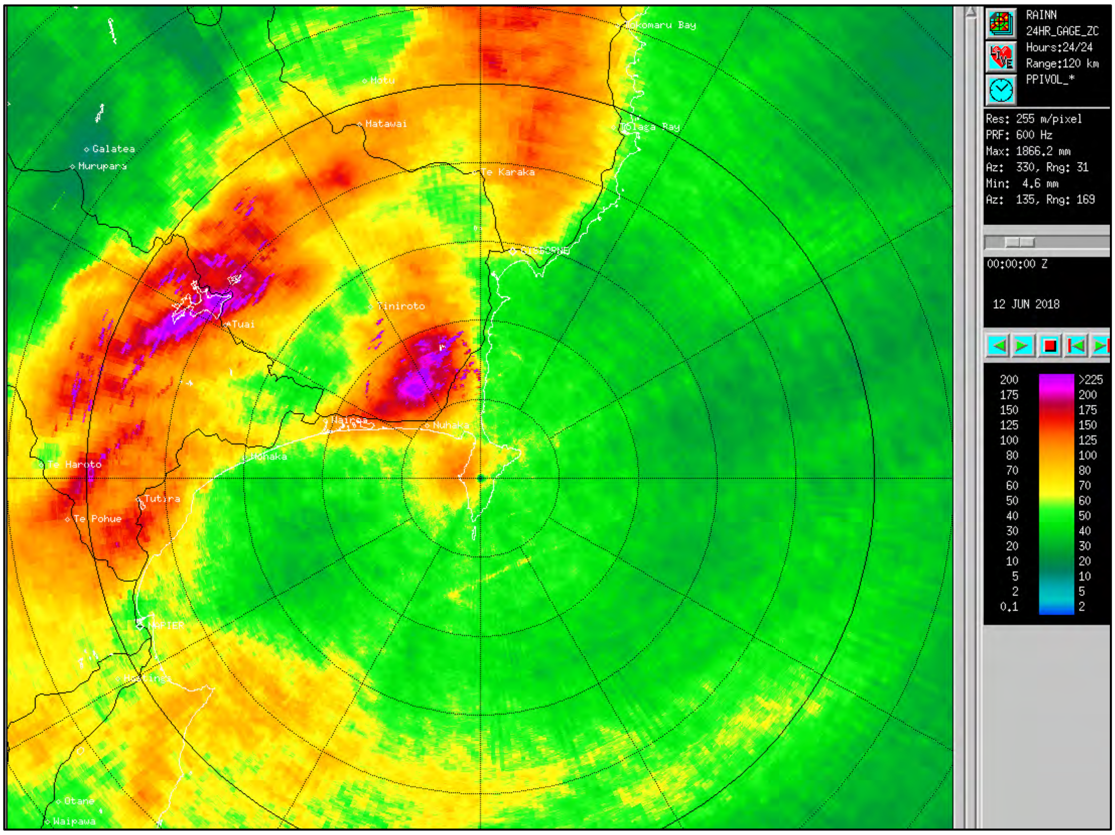


*Figure Thirteen.* *Rain radar image showing the 24 hour rainfall accumulation for the region for the period before midday on the 12th June (NZ time). This shows a significant accumulation over the Wharerata east of Mangapoike, north of the Waipaoa catchment and with a small cell south of Matawai.*

## Rainfall Accumulations by Catchment

Rainfall has been contoured based on the 12 hour period covering the heaviest rainfall (7pm on the 11th to 6am on the 12th) as well as the 24 period from 1pm on the 11th to midday on the 12th of June. As the storm was essentially a 24 hour event, this period is shown below (**Figure Fourteen**).

As noted above, the heaviest rainfall accumulations were in the Waiapu and catchments further north. In the far north rainfall of 216mm at Waikura dropped off to 48.2mm at Hicks Bay. The highest rainfall for the storm occurred at the northwestern edge of the Waiapu Catchment at Raparapaririki rain gauge. Rainfall dropped off to 101mm at Ruatoria and 55mm at the Poroporo Fire gauge. This band of rain extends to the southern eastern end of the Waiapu Catchment with the Puketawa rain gauge recording 199.8mm, Tutamoe 177mm, and Fernside 199mm over 24 hours. East of these gauges, the Mata gauge at Pouturu recorded 184mm while 117.5mm fell at Te Puia.

At the western edge of the Uawa Catchment, the Tauhu rain gauge recorded 173.5mm over 24 hours while the Mangaheia and Willowbank rain gauge recorded 89.5mm. The Hikuwai River at Willowflat recorded 89.5mm while Uawa River at SH 35 bridge recorded 60mm over 24 hours.

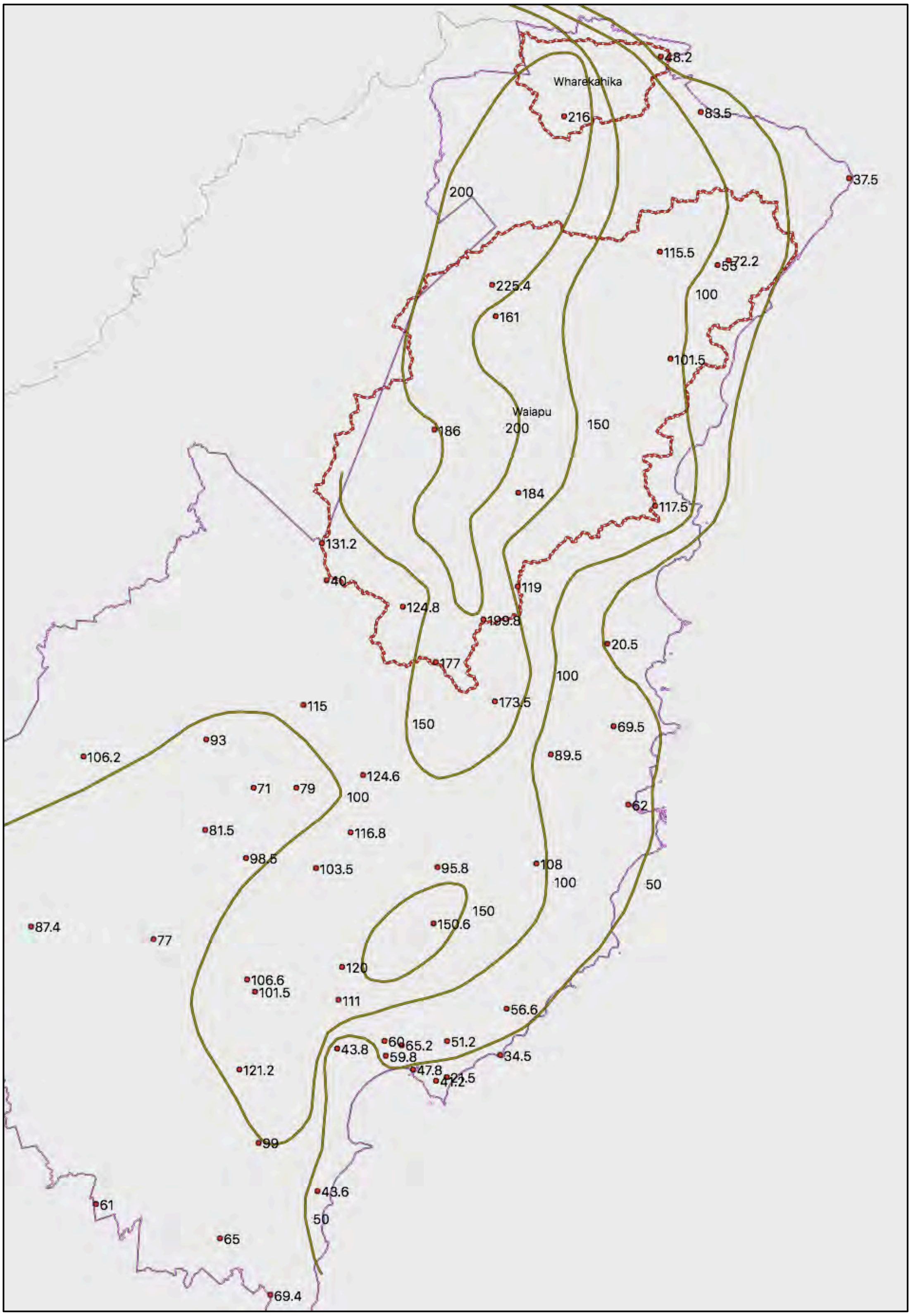


***Figure Thirteen.*** *Twenty four hour rainfall accumulations for the Tairawhiti region from 1pm on the 11th June to Midday on the 12th June.*

Over 100mm of rainfall over 24 hours fell in the northwestern headwaters of the Waipaoa particularly in the headwaters of the Waingaromai River. A peak of 150.5mm accumulated around the settlement of Waimata in the Waimata catchment over 24 hours while the Wakaroa rain gauge had 95mm of rain over the same period. Around 100mm fell widely over the western end of the Waipaoa Catchment as well as in the lower reaches extending as far as Te Arai and Pykes Weir. Further south and west of the Te Arai gauge, rainfall accumulations were less than 100mm over 24 hours and the Wharerata and Mangapoike gauges recorded rainfalls of between 65 and 69mm.

The Waipaoia Catchment experienced a flood that was the second highest since Cyclone Bola in 1988. This analysis suggests that this flood resulted not from intense peak rainfall accumulations but because of prolonged heavy rainfall over a 24 hour period. This would have been exacerbated by the event falling on a catchment that was already saturated after the Queens Birthday storm meaning that the ground had little storage capacity to buffer the rainfall with much running off into the catchment immediately.

**Average Recurrance intervals**

Hall and Boswell (2018) produced a summary of both the Queens Birthday (3-4$^{th}$ June) and Post Queens Birthday (11-12$^{th}$ June) storms. That report remained as an incomplete draft, however, and had a number of caveats noting many areas requiring further analysis. Thus this report uses the NIWA High Intensity Rainfall database (HIRDS) to determine the ARI of the storm.

*The Hirdsv4 Tool*

The Hirdsv4 Tool operated by the National Institute of Water and Atmospheric Research (NIWA) was used to generate indicated average recurrence intervals. The HIRDS tool provides a web map-based interface to enable rainfall estimates to be provided at any location in New Zealand. The web map also displays the locations of all rain gauges used in the HIRDSv4 analysis.

When a gauge is selected, a report can be generated and downloaded as a csv file. Whether a location is selected by clicking on a gauge, clicking anywhere on the map or using the input boxes makes no difference to the way the HIRDS tables are generated.

Rainfall estimates are generated in three steps.

1. *Selecting a location by either:*
    *searching using the Address Search*
    *clicking anywhere on the NZ map*
    *clicking one of the rain gauge locations*
    *entering the latitude, longitude and name (WGS84 coordinate system).*
2. *Select output format:*
    *depth-duration-frequency: returns the amount of rain fallen during the event (in mm).*

*intensity-duration-frequency: returns the average rate of rainfall during the event (in mm/hr).*

The downloaded data for each site also includes a simple calculator that allows for the ARI to be estimated by typing in the desired duration interval (in this case 24 hours) and a return period to match the Hirdsv4 data with the rain gauge data.

In this analysis, a suite of reports were generated and downloaded and then compared with actual rain gauge accumulations. Not all Hirdsv4 sites coincided with GDC rainfall gauge sites and where the same sites were used they may use different names; for example Hirdsv4 Pakarae @ Pakerae is the same as GDC Paniakau Reed road. Because, however, the Hirdsv4 tools allows for the interpolation of data using selecting a specific point on the ground, this option was used as it allowed for the ARI to be estimated at the 59 GDC rain gauge locations.

The twenty two rain gauges within the Waipaoa Catchment have been separately assessed since this catchment experienced severe flooding during the event. On an individual gauge basis, the Hirdsv4 ARI's for the Waipaoa range from 1 years to 12.2 years and have a median value of 10.8 years (**Table Two**). Hirdsv4 ARI's for the entire region are shown in **Table Three**.

| Station | 24 hour | 12 hour | 1 hour (max) | Hirdsv4 24 hour Ari |
|---|---|---|---|---|
| Caesar Rd No.1 Bore GPG058 | 120 | 99.6 | 13.6 | 5.8 |
| Hika No.1 Bore Ferry Road GPE032 | 111 | 96.5 | 15 | 5.6 |
| Komihana Station | 93 | 74 | 9.5 | 1 |
| Mangatu River at Omapere Station | 71 | 57.5 | 7.5 | 1 |
| Ngatapa school | 106.6 | 96 | 14 | 5 |
| Te Arai River at Pykes Weir | 99 | 82 | 11 | 1.85 |
| Te Rata Telemetry Station | 40 | 28.5 | 4 | 1 |
| Tuahu Station | 173.5 | 130.5 | 23.5 | 6.6 |
| Tutamoe Station Telemetry Station | 177 | 130.5 | 20 | 12.2 |
| Waerenga-O-Kuri | 121.2 | 99.4 | 13.8 | 3.3 |
| Waihora River at No.3 Br | 116.8 | 93.6 | 12.2 | 5.3 |
| Waikakariki Stream at Kirkpatrick Br | 101.5 | 91.5 | 14 | 1.47 |
| Waikohu River at Mahaki Station | 81.5 | 66.5 | 8.5 | 1 |
| Waikohu River at No.3 Br | 98.5 | 83.5 | 11 | 1 |
| Waingaromia River at Terrace Station | 124.6 | 96 | 13.2 | 10.8 |
| Waipaoa River at Kanakanaia | 103.5 | 87 | 11 | 5.8 |
| Waipaoa River at Matawhero Bridge | 43.8 | 33.2 | 5.2 | 1 |
| Waipaoa River at Te Hau Station Rd Br | 79 | 61.2 | 7.4 | 1.8 |
| Waipaoa River at Waipaoa Station | 115 | 80.5 | 11.5 | 6 |
| Wakaroa Trig | 95.8 | 73.4 | 10.8 | 3.7 |
| Wharekopae River at Rangimoe | 77 | 64.5 | 11 | 2.4 |
| Wharekopae School | 87.4 | 65.4 | 9.4 | 1.74 |

***Table Two.*** *Rain Gauge data for the Waipaoa Catchment showing site specific Hirdsv4 ARI's.*

| Station | 24 hr | 12 hr | 1 hr (max) | Hirdsv4 24 hour Ari |
|---|---|---|---|---|
| Arowhana Repeater | 131.2 | 96.8 | 12.6 | 1 |
| Caesar Rd No.1 Bore GPG058 | 120 | 99.6 | 13.6 | 5.8 |
| Cameron Rd No.1 Bore GPB099 | 60 | 47 | 8.5 | 1 |
| East Cape at Lighthouse | 37.5 | 12 | 6 | 1 |
| Fernside Station Telemetry Station | 119 | 85.4 | 11.2 | 2.75 |
| Hika No.1 Bore Ferry Road GPE032 | 111 | 96.5 | 15 | 5.6 |
| Hikuwai River at No 4 Bridge | 20.5 | 10.5 | 2 | 1 |
| Hikuwai River at Willowflat | 69.5 | 45 | 10 | 1 |
| Karakatuwhero River at SH35 Br | 83.5 | 43 | 15 | 1 |
| Komihana Station | 93 | 74 | 9.5 | 1 |
| Mangaheia at Willowbank | 89.5 | 64.5 | 9.5 | 1 |
| Mangapoike at Reservoir | 65 | 44.5 | 12.5 | 1 |
| Mangatu River at Omapere Station | 71 | 57.5 | 7.5 | 1 |
| Maraetaha River at No.3 Br | 43.6 | 33.4 | 6.2 | 1 |
| Mata River at Pouturu Br | 184 | 127.5 | 17.5 | 5.2 |
| Matawai Telemetry Station | 106.2 | 83.6 | 11.6 | 2.1 |
| Ngatapa school | 106.6 | 96 | 14 | 5 |
| Oates St Air Quality | 59.8 | 44.8 | 7.2 | 1 |
| Pakihiroa Telemetry Station | 161 | 110.5 | 20 | 2.06 |
| Panikau Rd - Reed Rd | 108 | 75 | 15 | 1 |
| Parone Rd RG | 41.2 | 28.8 | 5 | 1.4 |
| Poroporo Fire | 55 | 13.2 | 6.2 | 1 |
| Poroporo River at SH35 Bridge | 72.2 | 24.8 | 9.2 | 1 |
| Poroporo Telemetry Station | 115.5 | 56.5 | 12.5 | 1 |
| Pouawa Fire | 56.6 | 37.4 | 7 | 1 |
| Puketawa Station | 199.8 | 157.4 | 18.6 | 9.1 |
| Puketoro Telemetry Station | 186 | 125.5 | 22.5 | 4.8 |
| Raparapaririki | 225.4 | 161.6 | 29.2 | 4.25 |
| Ruatoria Telemetry Stn at Barry Ave | 101.5 | 50 | 11.5 | 1 |
| Stout St RG | 65.2 | 49.2 | 10.2 | 1 |
| Tatapouri Hill | 34.5 | 17.5 | 6.5 | 1 |
| Tauwhare Station | 124.8 | 94.4 | 13.2 | 1.7 |
| Te Arai River at Pykes Weir | 99 | 82 | 11 | 1.85 |
| Te Puia | 117.5 | 72 | 15.5 | 1 |
| Te Rata Telemetry Station | 40 | 28.5 | 4 | 1 |
| Tuahu Station | 173.5 | 130.5 | 23.5 | 6.6 |
| Tutamoe Station Telemetry Station | 177 | 130.5 | 20 | 12.2 |
| Uawa River at SH35 Bridge | 62 | 36.8 | 9.6 | 1 |
| Waerenga-O-Kuri | 121.2 | 99.4 | 13.8 | 3.3 |
| Waihora River at No.3 Br | 116.8 | 93.6 | 12.2 | 5.3 |
| Waikakariki Stream at Kirkpatrick Br | 101.5 | 91.5 | 14 | 1.47 |
| Waikanae Creek @ Customhouse St Br | 47.8 | 34.6 | 5.6 | 1 |
| Waikohu River at Mahaki Station | 81.5 | 66.5 | 8.5 | 1 |
| Waikohu River at No.3 Br | 98.5 | 83.5 | 11 | 1 |
| Waikura Valley | 216 | 140.5 | 26 | 3.16 |
| Waimata River at Goodwins Rd Bridge | 51.5 | 35 | 8.6 | 1 |
| Waimata River at Monowai Bridge | 150.6 | 121 | 17 | 4.6 |
| Waingaromia River at Terrace Station | 124.6 | 96 | 13.2 | 10.8 |
| Waipaoa River at Kanakanaia | 103.5 | 87 | 11 | 5.8 |
| Waipaoa River at Matawhero Bridge | 43.8 | 33.2 | 5.2 | 1 |
| Waipaoa River @ Te Hau Station Rd Br | 79 | 61.2 | 7.4 | 1.8 |
| Waipaoa River at Waipaoa Station | 115 | 80.5 | 11.5 | 6 |
| Wakaroa Trig | 95.8 | 73.4 | 10.8 | 3.7 |
| Whakapunake Trig | 61 | 46.4 | 5 | 1 |
| Wharekahika River at Hicks Bay Rd Br | 48.2 | 23.6 | 7.6 | 1 |
| Wharekopae River at Rangimoe | 77 | 64.5 | 11 | 2.4 |
| Wharekopae School | 87.4 | 65.4 | 9.4 | 1.74 |
| Wharerata at Radio Track Rd | 69.4 | 44.2 | 7 | 1 |
| Wheatstone Rd | 21.5 | 17 | 2.5 | 1 |

***Table Three.*** *Regional rain gauge data for the 11$^{th}$-12$^{th}$ June storm (cf Table One) with the Hirdsv4 ARIs.*

For the Waiapu Catchment the individual site Ari's range from 1 to 12.1 (Tutamoe Station) with an average ARI of 3.3 years but with half of the sites recording an annual sized event, the median ARI is 1.7 years. These Hirdsv4 rainfall ARI's do not appear consistent with the extent of flooding experienced in the Waipaoa or the flooding at the lower reaches of the Waiapu. Although as noted earlier the Hall and Boswell (2018) report was an incomplete draft it also noted a discrepancy when using Hirdsv3 tables to generate rainfall ARI's. This issue cannot be resolved here and further research is needed to resolve a meaningful return period for Tairawhiti high intensity storm events.

One element that has clearly impacted on the flood behaviour of the second storm is that it occurred just a week after the Queens Birthday storm meaning that ground saturation levels were very high. Consequently, the capacity of soils to store water were minimal and runoff was maximised.

**Analysis of Impacts**

The storm of 11th-12th June is beyond the scope of detailed analysis of the landslide impacts being undertaken by the Institute of Geological and Nuclear Sciences with focuses on the Queens Birthday storm. Google Earth Pro has just been updated, however, and now includes imagery dated the 25th of August 2018. This is a broader swath of imagery derived from that tasked for GNS on behalf of GDC and is produced at a lower resolution but covers a larger area.

In addition, lower resolution Sentinel satellite imagery dated 2nd of July 2018 have also been assessed for areas where the 25th August data is not available. Both image sets have been compared with pre-event imagery including Google Earth data dated 17th August 2017 as well as GDC aerial imagery captured over the summer of 2017-2018 has also been used to assess pre-event conditions.

This is particularly for part of the Waiapu catchment and the southern and western Waipaoa catchment. This data allows for an analysis of the relationship between the 11th-12th June rainfall accumulation with on the ground.

As noted above this storm had a significant impact on the region, particularly the Waipaoa. It also captured some national media attention but not as much as for the earlier Queens birthday event. Apart from the flooding in the Waipaoa, two significant events were reported as a result of this storm. These were the washout of Uttings Bridge on the Waimata Road and the influx of logging waste into the Mangapoike Lake[1].

[1] Mangapoike Lake refers to the new lake that formed in February 2018 and not the Mangapoike Reserviors.

*Waimata valley*

The washout of Uttings Bridge resulted in the closure of the Waimata Road for several days (See **cover photograph**). An initial Inspection at the Bridge and upstream was undertaken on the 16th of June 2018. An initial inspection at the bridge showed the presence of a large volume of newly deposited silt but also included pine logs, most of which were long resident logs[2] but with some logs showing sharp cut ends and Warratah marks. There was also some minor indigenous vegetation and some material with rootballs[3].

It was not safe to traverse the stream directly above Uttings Bridge and access was instead gained from the Halls property some distance upstream.

The stream was then traversed for 3 kilometres. It was found that the stream was full of logs, again a mix of older logs, quite a few cut logs and a few with warratah marks. There were also quite a few fallen pine trees in the stream where they had either been knocked down or undermined. It was established that there is at least 50,000 $m^3$ material in the stream which will cause problems in the future and should be removed. It was also established that the material had been sourced from further up the catchment than the last point that could be safely traversed.

The top of the catchment was then accessed along Duncan Road, a public road that traverses Wakaroa Forest. From Duncan road a series of forestry landing collapses could be observed above the area accessed during the stream traverse. The area was then traversed by helicopter on the 17th of June which confirmed that the source of the forest debris in the stream was the Wakaroa Forest.

Google Earth imagery of Uttings Bridge dated 17th of August 2017 and 25th August 2018 are shown in **Figures Fourteen** and **Fifteen** below. These indicate the extent of sediment deposited at Uttings Bridge during the storm. There are bright areas above the bridge in the August 2017 arising from flooding during ex-Cyclone Cook at Easter 2017 which caused some sediment mobilisation in the stream.

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[2] Long resident logs are pine logs which show signs of weathering and have abraded ends.

[3] Stems with rootballs are often referred to as windthrow, however, this investigation has established that logs with roots attached can be generated by several mechanisms. 1) Trees swept down slopes by debris flows, 2) trees dislodged from riparian margins as a result of the force of the flood of water and logs moving down the catchment, and 3) true windthrow where trees are blown over during wind events of downblasts and are then mobilised during storms.

***Figure Fourteen.*** *Google imagery of Uttings bridge dated 17th August 2017 showing the pre-event condition of the stream. The bright areas above the bridge are where flooding during ex-Cyclone Cook at Easter 2017 caused some sediment mobilisation in the stream.*

***Figure Fifteen.*** *Google imagery of Uttings bridge dated 25th August 2018 showing the extend of sediment deposited during the 11th-12th June 2018 event.*

Google Earth images for part of Wakaroa Forest (Hikurangi Forest Farms) dated 17th August 2017 and the 25th August 2018 have been examined to assess the impact of the storm in the forest and these have also been compared with the aerial photography Gisborne District Council acquired over the 2017-2018 summer.

Neither the 17th August image (**Figure Sixteen**) or the aerial photography (**Figure Seventeen**) both show significant landslide activity but the situation has changed by the 25th August 2018 image which shows significant landslide activity (**Figure Eighteen**).

Particularly evident from the 25th August 2018 image are the presence of landslides originating from skid sites, spur lines or roadways. This is consistent with the on-the-ground observations of damage and the probable causes of the slope failures.

A key feature of the image is that there is little damage within closed canopy forests or 10 year-old trees. The exception has been where landing collapses have caused debris flows which have migrated down slope to the stream bed and from there downstream. The presence of birds-nests of harvest waste evident in Figures Sixteen and Seventeen would have exacerbated the force of the debris flows.

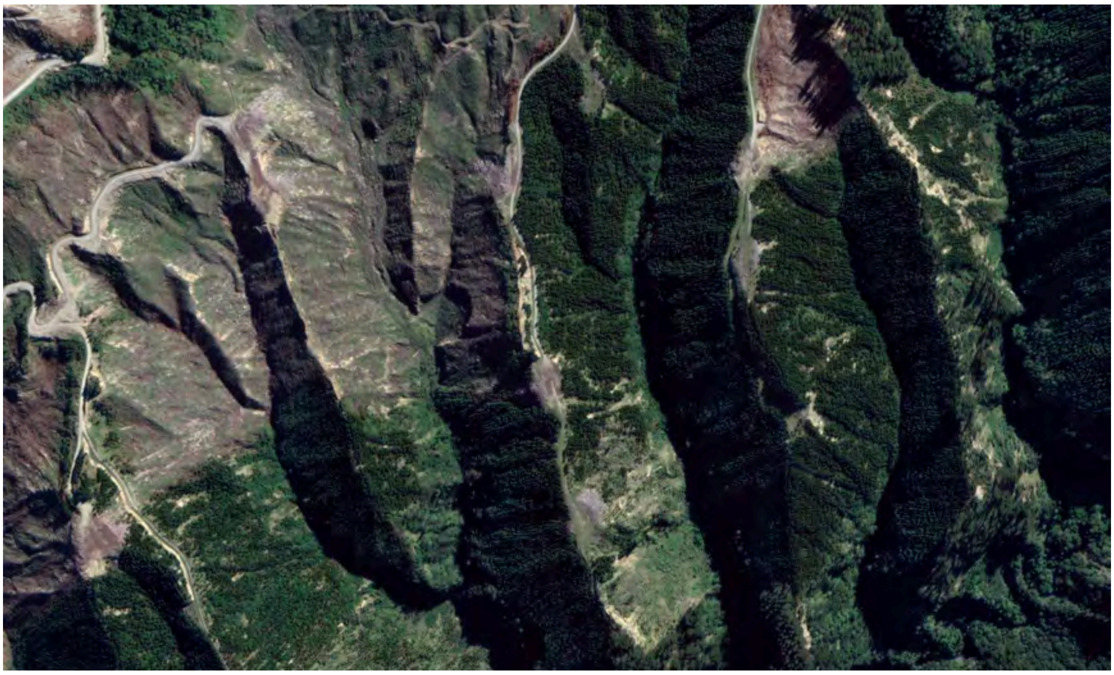

*Figure Sixteen. Google Earth image of the middle of Wakaroa Forest dated 17th August 2017 showing no significant slope stability issues. In particular the skid site at bottom left and top right.*


***Figure Seventeen.*** *Aerial image of the same area as Figure Sixteen (image acquired summer of 2017-2018) showing the skid site bottom left with no landslide activity and no evidence of fresh slipping elsewhere.*

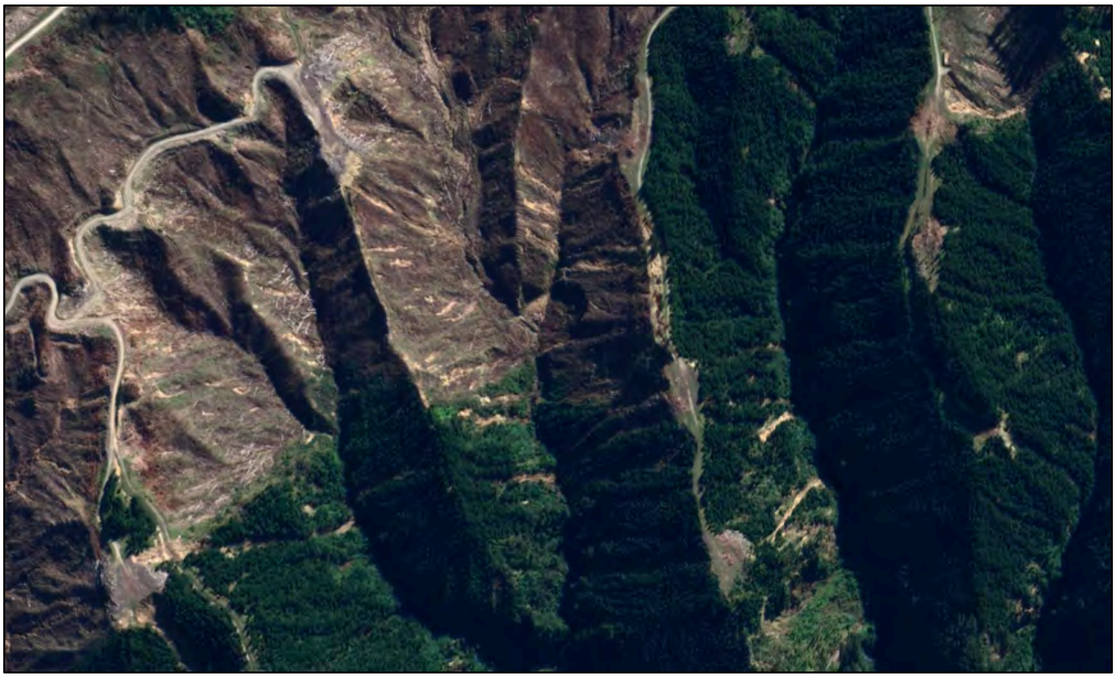

***Figure Eighteen.*** *Google Earth image of the Wakaroa Forest dated 25th of August 2018 showing the bright areas where collapses have occurred. A collapse from the western side of the landing at top right is not well evident due to being in shadow. It is notable that only a few "mid slope" type landslides have occurred.*

**Figures Nineteen** and **Twenty** below show details of the top right and bottom left landing sites described above respectively.

*Figure Nineteen. Detail of Figure Eighteen showing the debris flow from the top right landing (in shadow) on the lefthand side of the landing. Also more evident in the image are the slope failures generated on the righthand side of the landing.*

*Figure Twenty. Detail of Figure Eighteen showing the multiple collapses of the bottom left landing.*

The Makiri Forest is immediately north of Wakaraoa Forest and is immediately north of the Wakaroa rain guage which reported 95.8 mm over 24 hours during the storm of 11th 12th June 2018. The condition of Makiri Forest dated 17th August 2017 is shown in **Figure Twenty One** and shows the landscape in good condition, albeit with scarring from cable hauler activity. Gisborne District Council aerial imagery acquired over the summer of 2017-2018 shows the development that has occurred after August 2017. This shows that roadway development had continued but also shows that there's been no landsliding up until summer 2017-2018 (**Figure Twenty Two**).

Satellite imagery dated 25th August 2018, however, shows that significant landsliding has occurred since the summer of 2017-2018 (**Figure Twenty Three**). Notably there has been no slope failures from intact forest except for two failures from a forestry road in the north of the image. A detail of **Figure Twenty Three** is shown in **Figure Twenty Four** and shows that the landslide originated from the forestry road or from landing collapses which has caused the downslope mobilisation of harvest residues.

***Figure Twenty One.*** *Satellite image of Makiri Forest dated 17th August 2017 showing prestorm condition of the forest. Striations evident on the harvested slope are the result of dragging by cable haulers.*

***Figure Twenty Two.*** *Aerial Imagery acquired over the summer of 2017-2018 showing the extension of the main forestry road to the Northwest but also shows no sign of landsliding activity.*

***Figure Twenty Three.*** *Satellite Imagery dated 25th August 2018 showing extensive landsliding activity since the summer of 2017-2018 imagery.*

***Figure Twenty Four.*** *Detail of figure Twenty Three showing the main forestry road in Makiri Forest with significant slope failures originating from the roadway and in the top of the image from a landing with harvest waste discharged downslope to the waterway.*

One other forest was significantly impacted by the 11$^{th}$-12$^{th}$ June storm but there is no high resolution post event satellite imagery available. Because, however, the high resolution satellite imager acquired on the 25$^{th}$ of August did not extend as far southest as Waituna, 10m resolution Sentinel 2 (NDVI [normalised difference vegetation index] B8-B4 /B8+B4 bands) data have been used to estimate damage occurring in Waituna. These bands are used as they highlight the degree of vegetation loss (essentially increased reflectance as vegetation is lost) over time.

The first image used was taken on the 23$^{rd}$ of April UTC time which is 24$^{th}$ of April 2018. The image, although low quality shows only limited a small number of slope failures in the recent harvest area (**Figure Twenty Five**). The second image is dated 6$^{th}$ June NZ time and shows an increase in reflectance indicating that significant damage occurred in the 3$^{rd}$-4$^{th}$ June Queens Birthday Storm (**Figure Twenty Six**). Since, however, JNL only reported an event after the 11$^{th}$-12$^{th}$ June event, it is presumed that material was mobilised but no significant harvest was discharged out of the forest until the 11$^{th}$-12$^{th}$ June event.

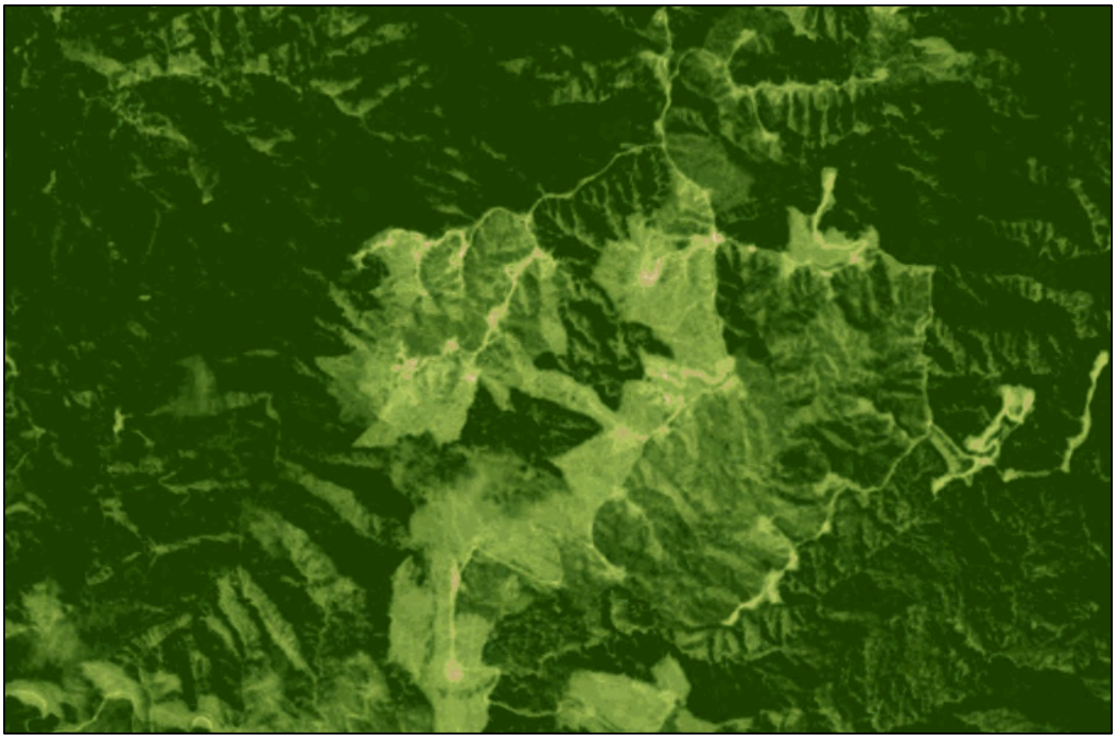

***Figure Twenty Five.*** *Sentinel 2 NDVI image of Waituna forest dated 24th of April 2018 prior to the Queens Birthday and 11th-12th June storms. Dark areas are intact forest, bright areas are roadways and skid sites, pale green are recent harvest areas while areas in between the pale and dark green are earlier harvest areas.*

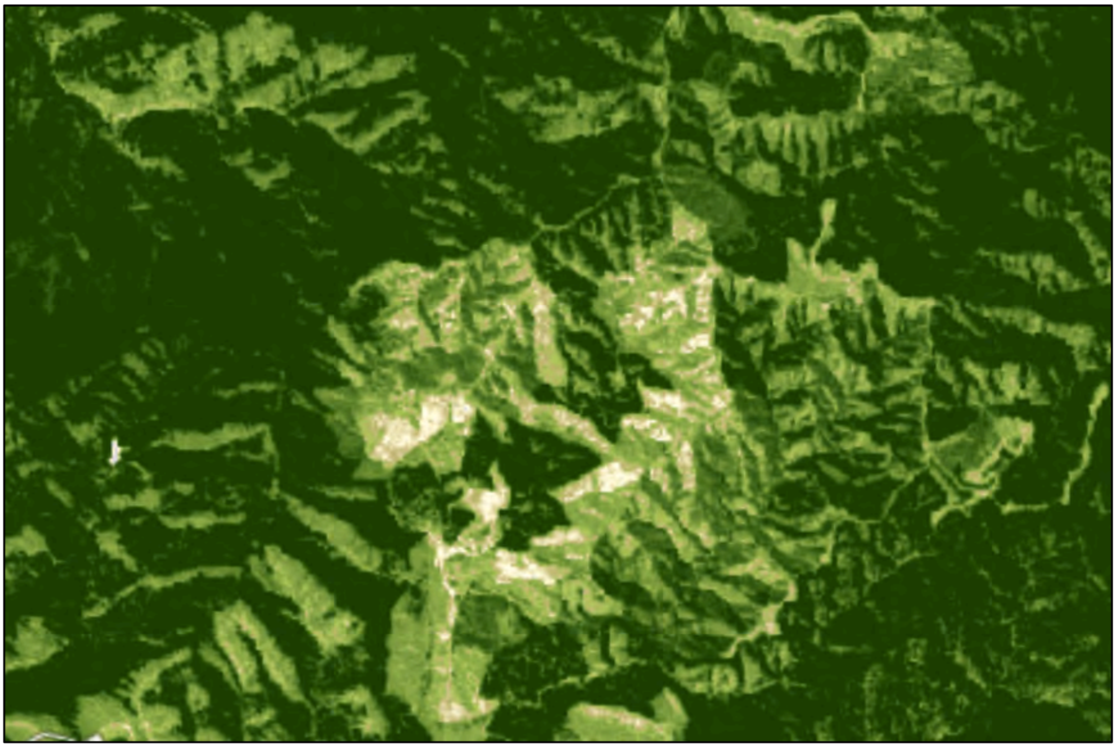

***Figure Twenty Six.*** *Sentinel 2 NDVI image of Waituna forest dated 6th of June 2018 immediately following the Queens Birthday storm. Evident are the new highly reflective areas indicating areas of bare earth after slips.*

An image dated 16th June New Zealand time shows a further change in the area of reflectance over the 6th of June largely through enlargement of reflective areas evident on the 6th of June. Some new areas of high reflectance are evident in the top middle-left of the image.

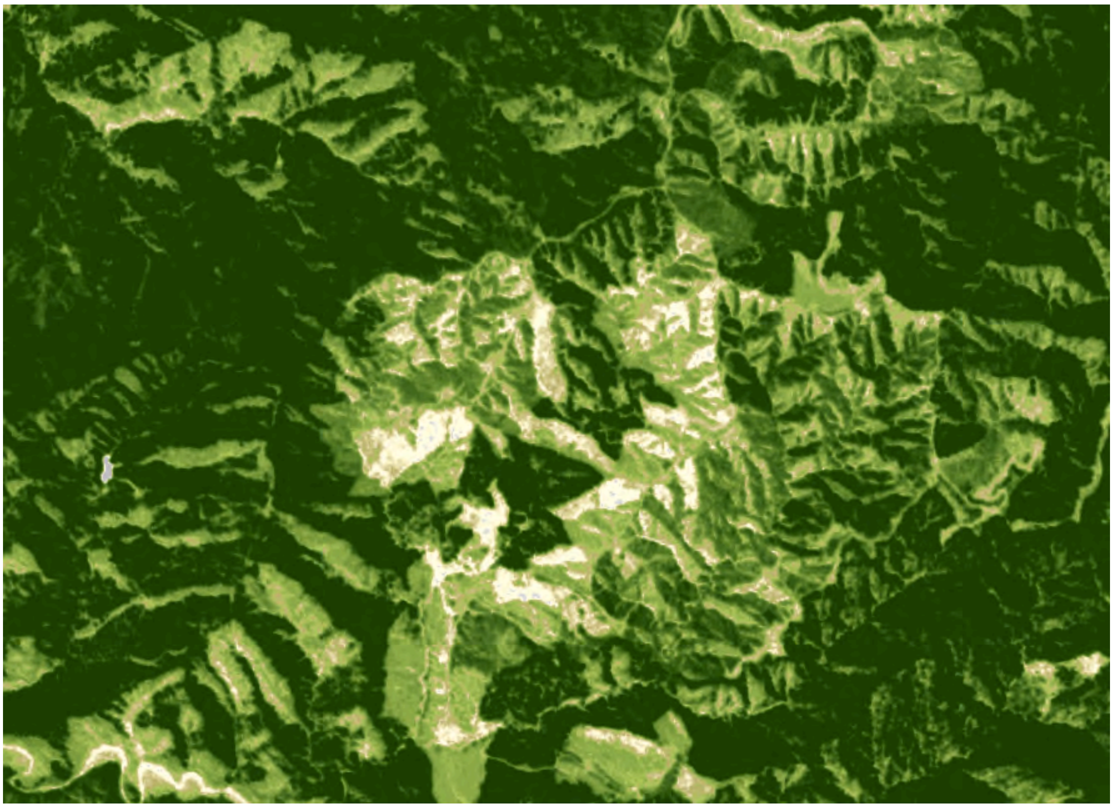

***Figure Twenty Seven.*** *Sentinel 2 NDVI image of Waituna forest dated 16th of June 2018 NZ time showing the enlargement of highly reflective areas as well as additional areas of reflectance, particularly at top middle-left.*