Assessment of July 2020 flood in Northland

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Abbreviation

ARI	Average Recurrence Interval
SPI	Standardised Precipitation Index
IDF	Intensity-Duration-Frequency
HIRDS	High Intensity Rainfall Design System
HEC-HMS	Hydrologic Engineering System
FDC	Frequency Duration Curves
SAM	Southern Annular Mode
IOD	Indian Ocean Dipole
ARs	Atmospheric rivers
NRC	Northland Regional Council
NIWA	National Institute of Water & Atmospheric Research
Met	MetService
NCEP	National Centres for Environmental Prediction
MOATA	Mott MacDonald Portal

Executive Summary

The July 2020 storm was driven by an active trough moving southeast from the north Tasman Sea against a blocking zone of high pressure to the southeast of the country. This storm spread through Northland and became concentrated in eastern parts of the region, leading to heavy rain and flooding in these areas for three days, 15–18 July 2020.

Rainfall was most intensified in northern Kaikohe, Waitangi, and Whangārei areas with over 100 mm fall in 6 hours and over 200 mm in 24 hours. Notably, rainfall recorded at Kaikohe rain gauge exceeded 100-year Average Recurrence Intervals (ARIs) for all short periods, 30 minutes to 24 hours. This triggered the rainfall severity in these areas during the entire storm period. Whangārei area received over 400 mm in three days that exceeded 106-year ARI estimated at Hātea rain gauge. Northern Kaikohe received 380 mm exceeding 96-year ARI estimated at Kaikohe rain gauge during the same period. Waitangi catchment received over 350 mm rainfall in three days exceeding its 1-in-50-year estimate at Ōhaeawai rain gauge.

The July 2020 flood severity followed the rainfall patterns. Flooding was widespread in the east during the storm. Hātea river had highest flows on record, however, this was likely influenced by tide. Our calculations suggested the actual peak flows in Hātea river between the 1-in-20-year and 1-in-50-year estimate. Similar flood severity was also found for Waitangi River with peak flows ranged between the 1-in-25-year and 1-in-50-year estimate. Notably, flood peak flowing through Raumanga stream into Whangārei CBD were reduced by about 20% due to the operation of Hopua te Nihotetea detention dam.

The July 2020 flood was not preceded by high Standardised Precipitation Index (SPI) but by very extreme short-term rainfalls, and well saturated antecedent soil condition. Compared to historic major floods in July 2007, January 2011 and July 2014, the July 2020 flood was, in general, less severe.

This report only focuses on key characteristics of the July 2020 storm flood without explicitly quantifying flood impacts. Further explorations are recommended for better monitoring of storms-floods as well as for increasing predictive capability around storm-flood conditions. These explorations include:

- Examination of trends and projections on the frequency and magnitude of extreme rainfalls and floods.
- Categorisation and characterisation of storms, extreme rainfalls, and floods.
- Quantification of the impacts of large-scale atmospheric variability (SAM, ARs, etc.) on extreme rainfalls and floods.
- Development of flood forecasting using rain radar, satellite data, large-scale atmospheric processes.
- Modelling of flood inundation and mapping of flood extent.

It is worth noting that Northland weather rain radar detected storm rainfall with similar severity in two areas, north Kaikohe and Whangārei, during the storm event. Whist, Northland Regional Council (Council) rainfall network only captured the Whangārei severe storm rainfall. This is because the Council network does not cover every single catchment in the region. Therefore, it is critical to use rain radar for storm monitoring and nowcasting together with the Council rainfall network.

Introduction

After a prolonged drought from July 2018 to June 2020, Northland experienced a severe storm in July 2020 (between 15 to 18 July 2020). This event triggered extremely heavy rainfalls and high flood flows in many areas across the region.

This report aims to provide key characteristics of July 2020 storm and its impacts on Northland rivers as outlined below:

- Assessment of the antecedent conditions prior to the event.
- Temporal and spatial analysis of rainfall data.
- Temporal and spatial analysis of flow data.
- Comparative evaluation of the current event to the historic 2007 and 2011 events.
- Investigation of drought-flood relationship.
- Identification of uncertainty/limitation if any.

Data and information from various sources were used in compiling this report.

Figure 1: Flooding near Whangārei 18 July 2020 (Source: Whangārei flying club).

Data availability

Data and related information from Northland Regional Council (Council), MetService (MET), and National Institute of Water & Atmospheric Research (NIWA) up to 1st Aug 2020, and during the 15 – 18 July 2020 event were compiled for this assessment. These included rainfall, flow, soil moisture data, storm, flood and weather information, and images.

Meteo-hydrological data was collected and checked by the Council's Hydrology team. Flood level data was surveyed by the Council's River team.

Rainfall

Long-term rainfall data from 45 rain gauges in Northland (automatic), and rain radar during the July storm-flood event were used for data analysis. The location of Northland rain gauges for which data were available are listed in Appendix 1. Rain radar is available on MOATA (Mott McDonald) portal for Northland Regional Council.

Soil moisture

Soil moisture deficit estimated by NIWA for its six climate stations were used (Appendix 2). This data was estimated from climatic parameters.

River flow

Long-term flow data at 30 Northland River monitoring stations was assembled. This data was transformed from recorded levels to flow rates or discharges. The station locations are listed in Appendix 3.

Flood gauging were carried out during the event at various locations.

Other data

Large-scale weather and climate information was obtained from National Centres for Environmental Prediction (NCEP). Remotely sensed data was extracted from Envirolink (Transferring scientific environmental knowledge to councils) tools (MBI, 2021). Modelled flood extents at 1-in-10-year and 1-in-50-year ARIs were extracted from Northland regionwide river flood models.

Methodology

Both statistical and numerical methods were applied for assessment of July 2020 flood in Northland. These methods included:

- Assessment of antecedent conditions: Rainfall and moisture conditions prior to the July storm was examined to identify the key drivers of river flood propagation and development processes. Drought monitoring indication (Standardised Precipitation Index, SPI) maps were also used in this regard.
- Storm tracking: Cumulative plots and hyetograph overplots for auto rain gauges were prepared to understand storm patterns. Rain radar imagery captured during the event was also used.
- Storm rainfall mapping: Storm depths for different durations, 30 minutes, 60 minutes, 1 hour, 3 hours, 6 hours, 1- to- 3 days were mapped to feature both the temporal and spatial distribution of the storm rainfall across the region.
- Storm rainfall characteristics: A series of intensity-duration-frequency plots (IDFs) was generated to exhibit the relationship of rainfall intensity with its duration and frequency of occurrence. This was also compared to a nationwide design storm (HIRDS) developed by NIWA. Average Reoccurrence Interval (ARI) maps were produced to display the severity of storm rainfall event.
- Flood characteristics: Similarly, hydrograph overplots and flow duration curves (FDCs) were produced to feature how the flood flows change with time and being compared to historic established flood events. ARI maps of storm rainfall and flood flow were overlayed to identify the most affected areas.
- Long-term variability: Relationship between large-scale circulations and local conditions were examined where appropriate.

Antecedent conditions

Antecedent moisture and rainfall conditions are key contribution towards the severity and frequency of a flood. Depending on the catchment characteristics, the influence of antecedent conditions on the flood can be between 7 days, 6 months and up to 12 months (McEnroe, Bruce; Gonzalez, Pablo, 2003; Kim & Chandrasekar, 2019).

This section provides information on rainfall and soil moisture state prior to the July storm event in Northland at different time scales.

Rainfall

June 2020 was a wet month for Northland with all locations receiving normal or above normal rainfall (Figure 1). This sets an end for a long drought in the region which commenced in July 2018. The Northland Standardised Precipitation Index (SPI) for the month showed that the region was near normal to moderately wet for the month (Figure 3). However, the long-term rainfall numbers showed that Northland still retained a rainfall deficit over the 12 and 6-month periods. The west coast had the highest deficit over the 6-month period, as this area benefits a lot less from north-westerly systems (Figure 4).

Soil moisture deficits

In the last two years (from July 2018 to June 2020) soil moisture levels were, in general, lower than normal long-term averages (Appendix 3). This means the soil had been in dry conditions throughout the drought period for all seasons. Conditions had changed slightly in some locations by the end of June 2020, the last month of drought. Soil moisture at Kerikeri, Kaikohe and Whangārei stations were at and above its normal June level, indicating that these catchments were well saturated.

Seven days prior to the storm, soil moisture deficit was at or above field capacity at all stations (Table 2 ; Appendix 4). In other words, the soil had been well saturated or antecedent conditions had become wetter before the storm hit, suggesting that the runoff and resulting floods would have been higher.

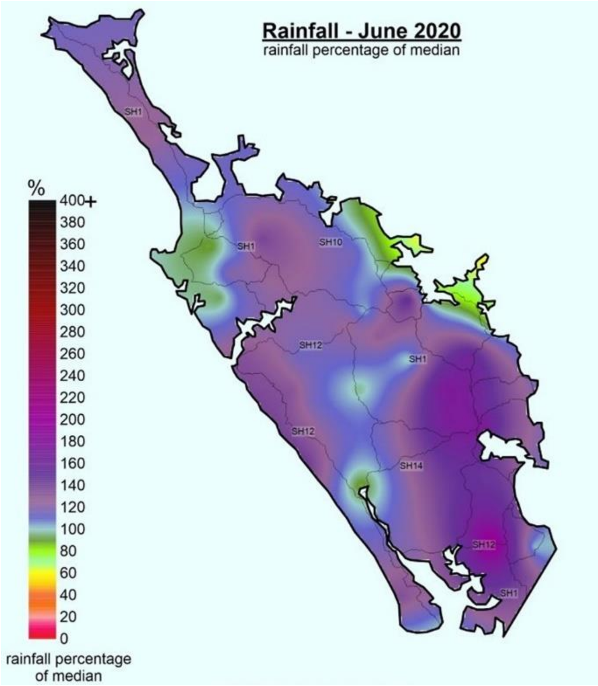


Figure 2: Rainfall map for June 2020.

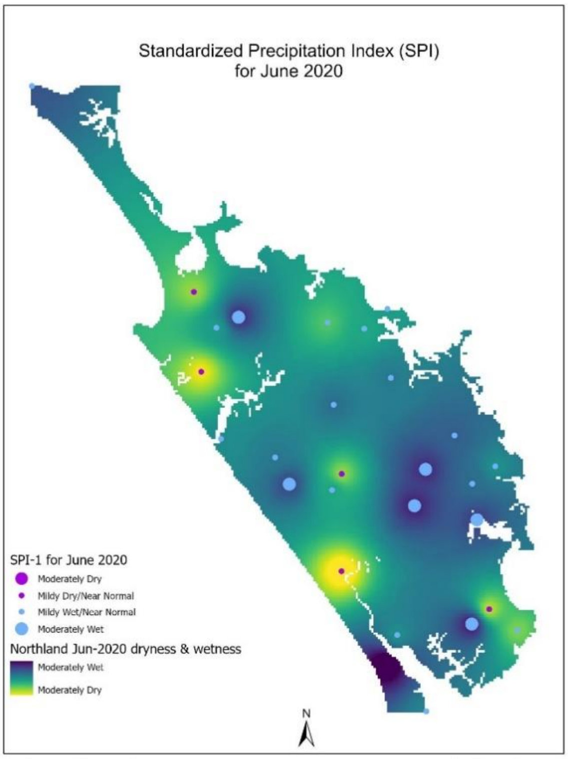


Figure 3: Meteorological Drought indication maps.

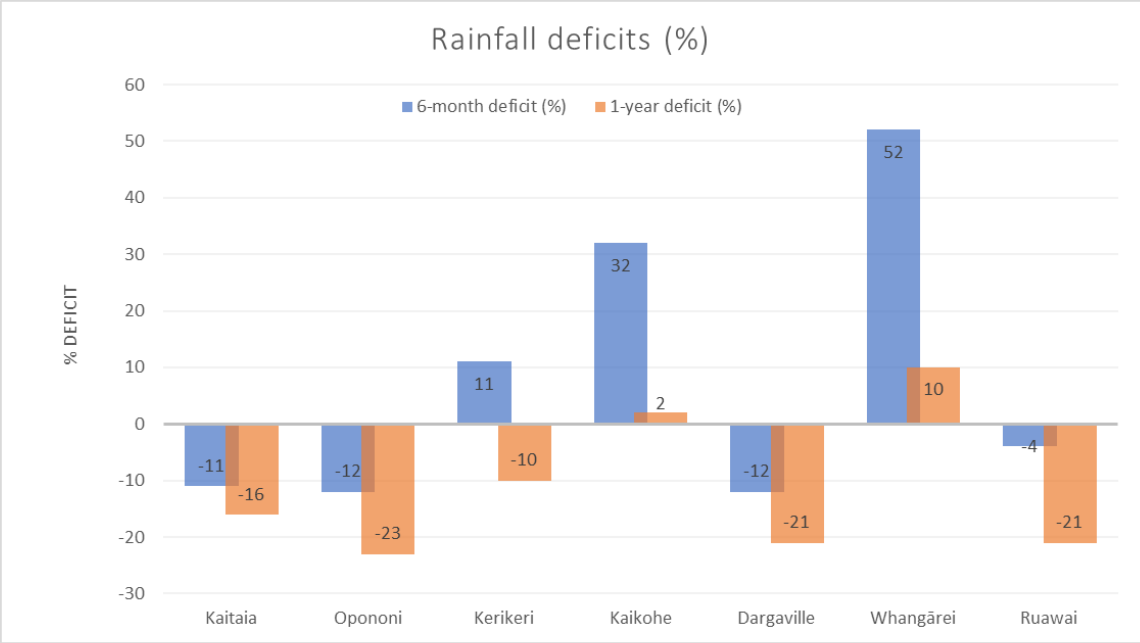


Figure 4: One year and six-month rainfall deficit at selected rain gauges.

Table 1: Soil moisture deficits as of 7th of July 2020.

NIWA Climate Station	Observed Soil moisture deficit	Mean June soil moisture deficit	Difference between Expected and Average
Kaitaia	0-25 mm	0 mm	0
Kerikeri	0-25 mm	0 mm	0
Whangārei	0-25 mm	0 mm	0
Kaikohe	0-25 mm	0 mm	0
Dargaville	0-25 mm	0 mm	0
Warkworth	0-25 mm	0 mm	0

Note: SMD is calculated based on incoming daily rainfall (mm), outgoing daily potential evapotranspiration (PET, mm), and a fixed available water capacity (the amount of water in the soil 'reservoir' that plants can use) of 150 mm (NIWA)

Storm descriptions

Large-scale earth surface circulation that formed a storm over Northland region during 15 to 18 July 2020 event is presented in Figure 5. There was a low-pressure or depression system on 15 July in the north of the Tasman Sea. The centre of the system moved southeast towards Northland on the next day, bringing storm and rainfall to the region. On its way, the depression system gained strength until 18 July 2020. At the same time, on 15 July, a high-pressure system was located northeast and southwest of Tasman Sea. This system extended out northeast on 16 July and moved to South Island of New Zealand on 17 July 2020.

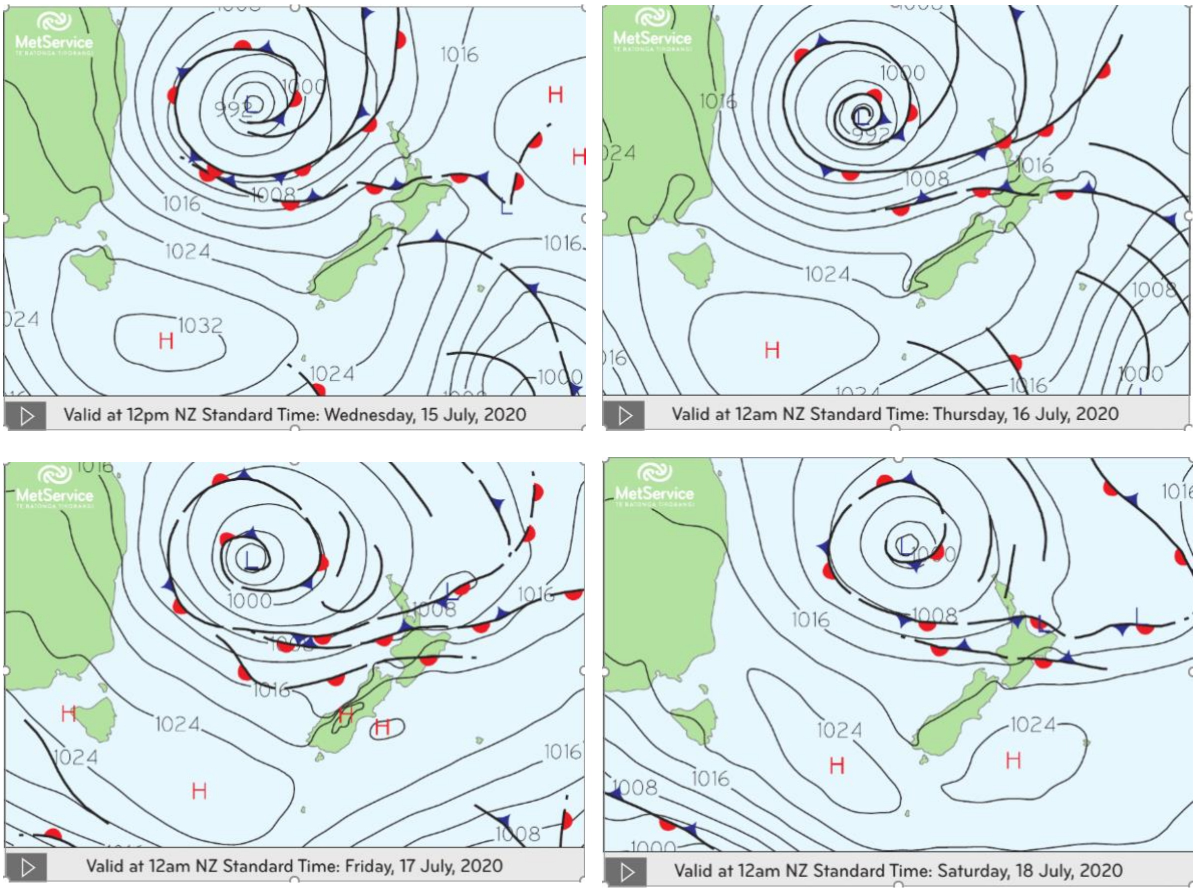


Figure 5: Surface pressure map for 15–18 July 2020 (pressures are measured in millibars).

Storm rainfall

This section describes the 15 to 18 July 2020 storm by its pattern, intensity, and frequency. Rainfall depths up to 3 days for various return periods (IDF – intensity depth frequency, ARI – average recurrence interval) at rain gauges were tested and selected ARIs were mapped. Comparison to historic events was also made where appropriate.

Storm rainfall patterns

The severe weather began as a moderate event on 15 and 16 July over the region, followed by a day of slight rain for the remainder of 16 July, and a long series of intense storm cells from early morning of 17 July until the midday of 18 July. These storm cells began in Waitangi catchment. It later spread throughout the region and became concentrated around Whangārei (Figure 6).

Similar patterns are also shown in Metservice radar images with a lag in time (Figure 7). The lag could be due to the time difference between MET radar and rain gauges at which they operate (UTC + 12 NZST). It is worth noting that MET ground-based radars measure precipitation from space over land while rain gauges measure precipitation that falls on land (rainfall) at given locations.

Storm rainfall intensity and frequency

Analysis of IDFs and ARIs at rain gauge location were used to statistically describe severity (intensity and frequency) of storm rainfall. Rainfall frequency estimates were based on extreme value Type-1 and generalized extreme value distributions fitted using L-Moment's method to series of annual maximum rainfalls.

The maximum rainfall for 30 minutes up to 3 days is shown in Table 2 & Figures 8, 9 & Appendix 5 & 7. The spatial distribution of changes in rainfall intensity increased uniformly across Northland, where Waitangi and Whangārei areas received the large amount of rain in short time.

- Maximum rainfall in Whangārei was recorded at Hātea Glenbervie Forest rain gauge with 60 mm and 73 mm recorded for 30 minutes and 1 hour, respectively.
- Maximum rainfall recorded at Waitangi Ōhaeawai rain gauge was 39 mm and 52 mm for 30 minutes and 1 hour, respectively.
- Rainfall recorded at all rain gauges in Waitangi and Whangārei areas exceeded 100 mm in 6 hours.
- Whilst Kaipara Harbour received the least rain with 7 mm, 14 mm and 28 mm recorded for 30 minutes, 1 hour and 6 hours, respectively at Dargaville rain gauge.

Increase in duration of rainfall lead to increase in depth of rain. Accumulative rainfall over three days is highest in Whangārei and its northern catchments with maximum total of 457 mm. Waitangi catchment received the second highest rainfall with maximum total of 359 mm, and Kaipara Harbour received the least rainfall of 101 mm total in three days as recorded at Dargaville rain gauge. Overall, majority of Council's gauges recorded over 100 mm rain during the storm period.

The severity of storm rainfall is presented in terms of return periods (ARIs) in Table 4. The severity of the storm was highest in Whangārei, the northern catchments of Whangārei, and then followed by Kaikohe and Waitangi areas.

- Recorded rainfall at Hātea Glenbervie falls between a 62-year and 106- year ARIs for both short and longer periods, 10 minutes to three days respectively.

- Rainfall recorded at Waitangi Ōhaeawai is estimated between 73-year and 50- year ARIs for both short and longer periods, 10 minutes to three days respectively.
- Rainfall recorded at Kaikohe rain gauge was second highest on record exceeding 96-year and 100-year ARIs during the same periods.
- Only rainfall in Whangārei area exceeds its estimate of three days at one-in-100-year return level. However, the highest return period rainfall intensity was estimated for shorter periods, between 30 minutes and 6 hours, in all three affected areas.

In contrast, the lowest intensity of storm rainfall was recorded in the West. Rainfall recorded at Dargaville rain gauge was estimated at 1-year ARI level for all above periods.

The spatial depiction of rainfall ARIs also proves that the severity of rainfall was triggered by rainfall intensity rather than rainfall total (Figures 9, 10 & Appendix 6 & 7). Despite the high rainfall total (100 mm and greater over 3-day storm duration) distributed for the most parts of Northland, the most severe storm rain concentrated in Whangārei, Kaikohe, and Waitangi areas. Notably, similar degree of rain severity was recorded for Whangārei, Kaikohe areas. The severity of rainfall in Kaikohe was higher than that in Waitangi even though rainfall in Kaikohe was not as high as what a nearby Waitangi Ōhaeawai rain gauge recorded.

Comparison of rainfall intensities for different periods with 100-year estimates was made at selected rain gauges (Appendix 5 & 7). Note, the record length of rainfall data has a considerable effect on rainfall estimation, the longer the data, the better the estimation is.

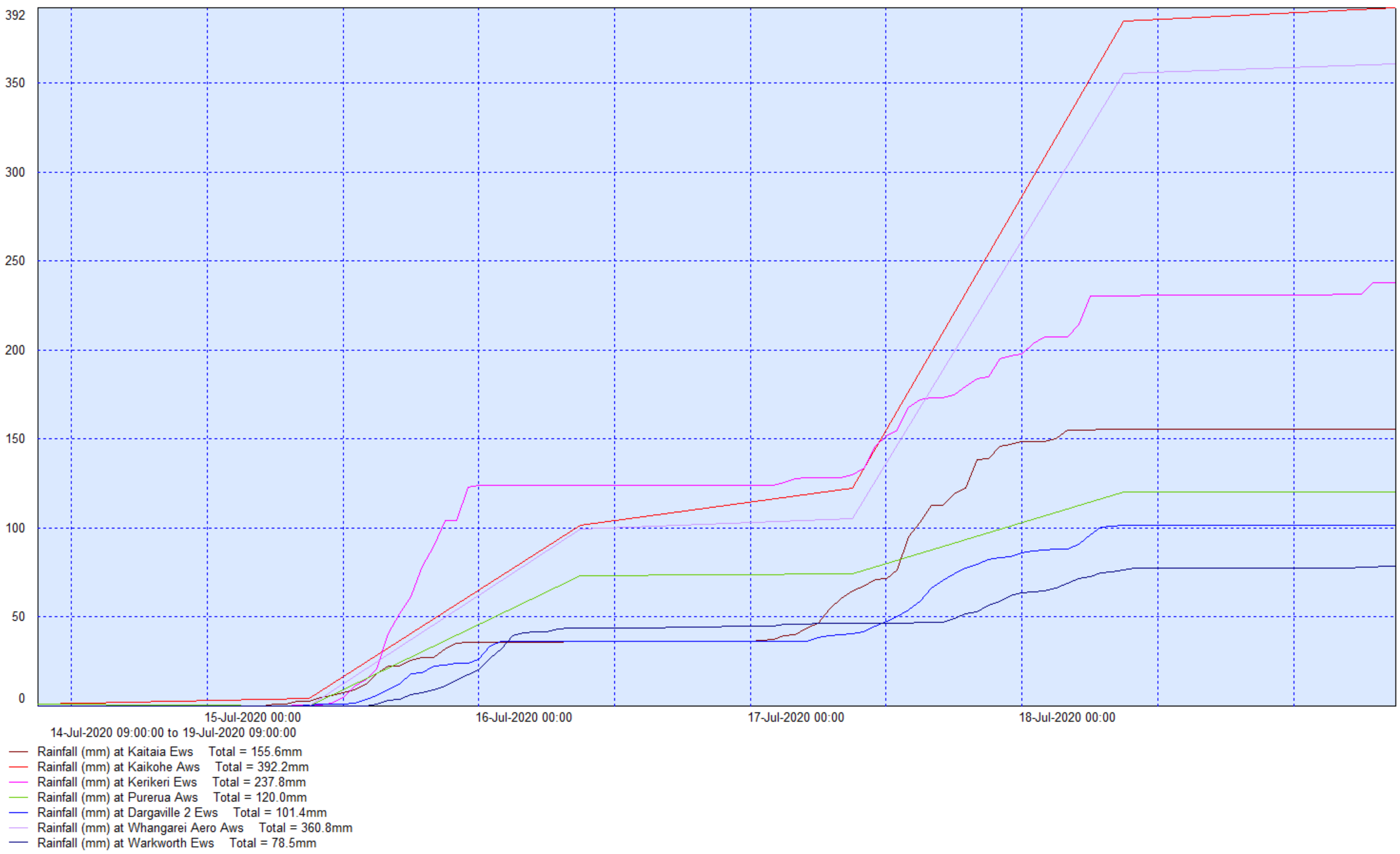


Figure 6: Cumulative rainfall between 15 and 19 July 2020 at selected rain gauges.

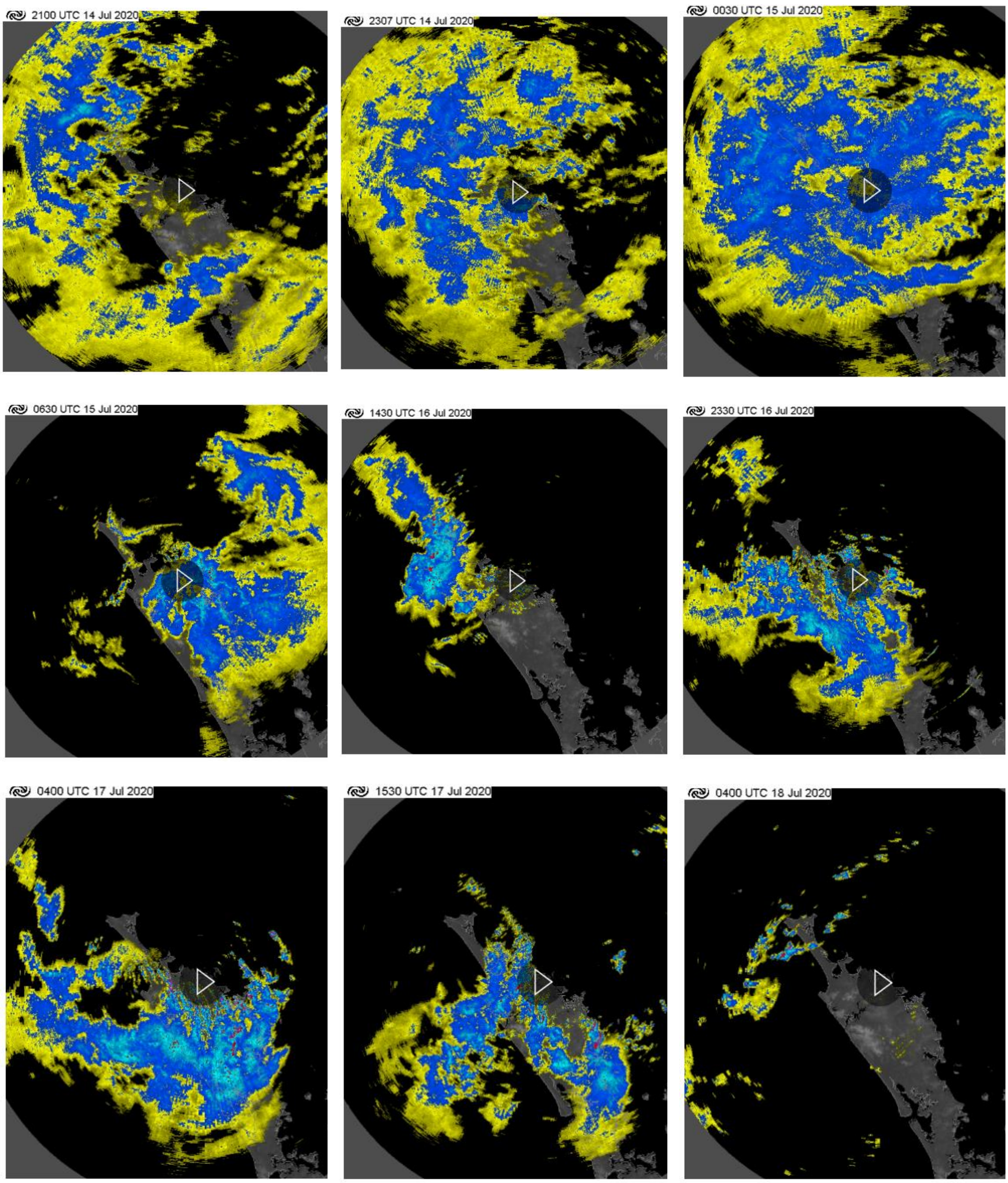


Figure 7: Storm captured by Northland radar between 14 and 18 July 2020 (UTC time): high intense precipitation is shown in blue.

Table 2: Maximum Rainfall intensity (mm) during 15-17 July 2020 at selected rain gauges.

Gauge	Duration					
	30 mins	1 hour	6-hours	12-hours	1-day	3-days
Cape Reinga	1.4	3	17	37	55	100
Tarawhataroa at Larmer Road	19	25	54	80	115	150
Kaeo at Bramleys	30	37	67	81	105	189
Kaikohe	5.5	10.9	65.5	131	209	380
Waitangi at Ōhaeawai	41	47	118	191	239	359
Hokianga harbour at Omapere/Opononi	17	24	45	52	59	73
Ngunguru at Dugmores Rock	39	52	140	197	235	362
Whakapara at Puhipuhi	49	68	177	220	273	434
Hātea at Glenbervie Forest	60	73	204	247	291	442
Waiarohia at Northland Regional Council Water Street	51	76	148	184	210	293
Dargaville	7	14	28	42	61	101
Warkworth	6	13	28	38	56	78

Table 3: Frequency analysis of storm rainfall during 15-17 July 2020 at selected rain gauges (ARI in years)

Gauge	Duration					
	30 mins	1 hour	6-hours	12-hours	1-day	3-days
Cape Reinga	2	2	2	2	2	2
Tarawhataroa at Larmer Road (*)	2	1	1	2	3	3
Kaeo at Bramleys (*)	10	5	1	1	1	3
Kaikohe	100	100	107	108	108	96
Waitangi at Ōhaeawai (*)	73	57	15	30	30	50
Hokianga harbour at Omapere/Opononi (*)	1	1	1	1	1	1
Ngunguru at Dugmores Rock	10	10	10	15	10	25
Whakapara at Puhipuhi	48	42	62	43	33	91
Hātea at Glenbervie Forest	62	76	74	65	84	106
Waiarohia at Northland Regional Council Water Street (*)	45	55	13	11	8	15
Dargaville	1	1	1	1	1	2
Warkworth	1	1	1	1	1	5

Note: (*) Estimation of high return period storm rainfall at this rain gauge is subjected to its data length.

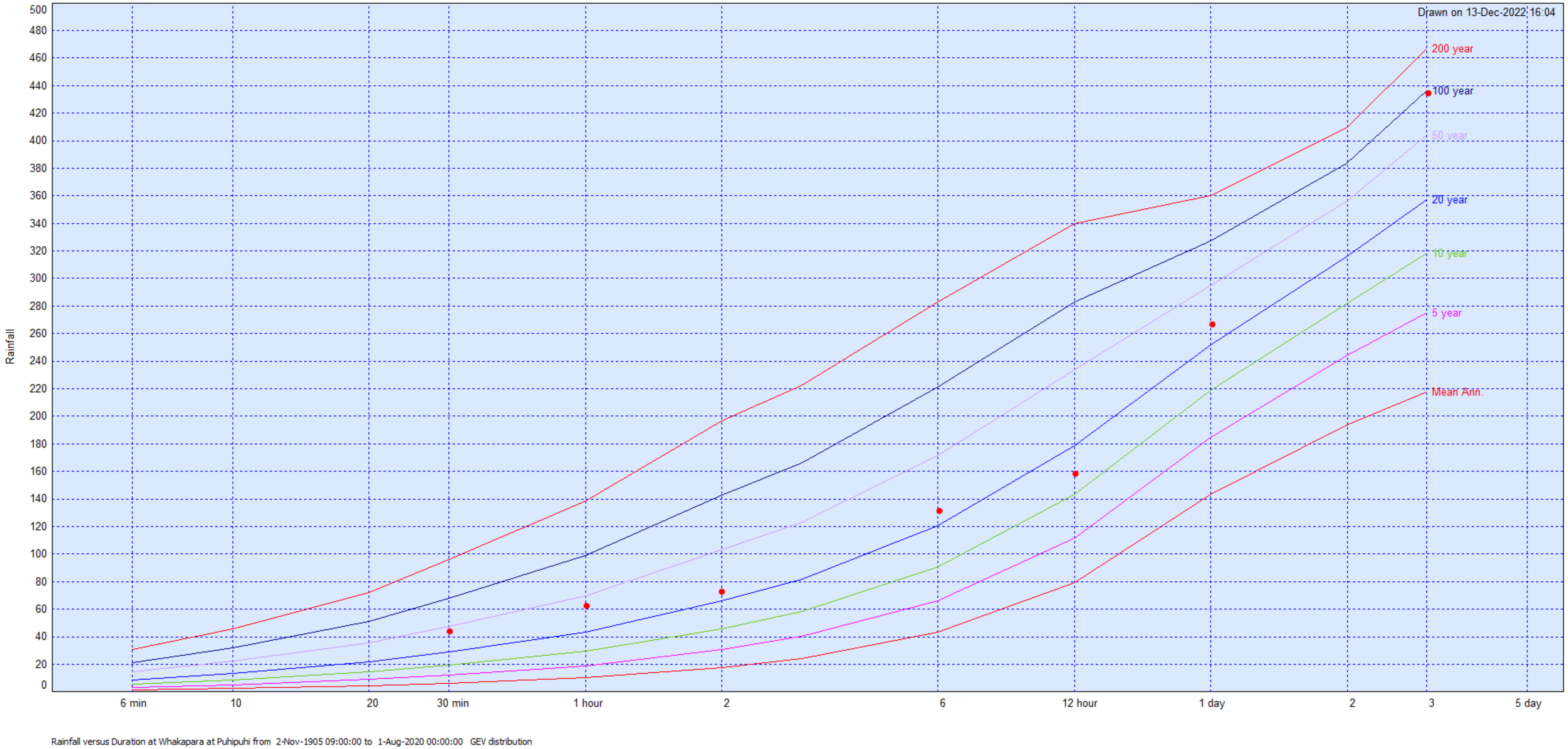


Figure 8: Intensity-duration-frequency (IDF) plot for Whakapara at Puhipuhi rain gauge.

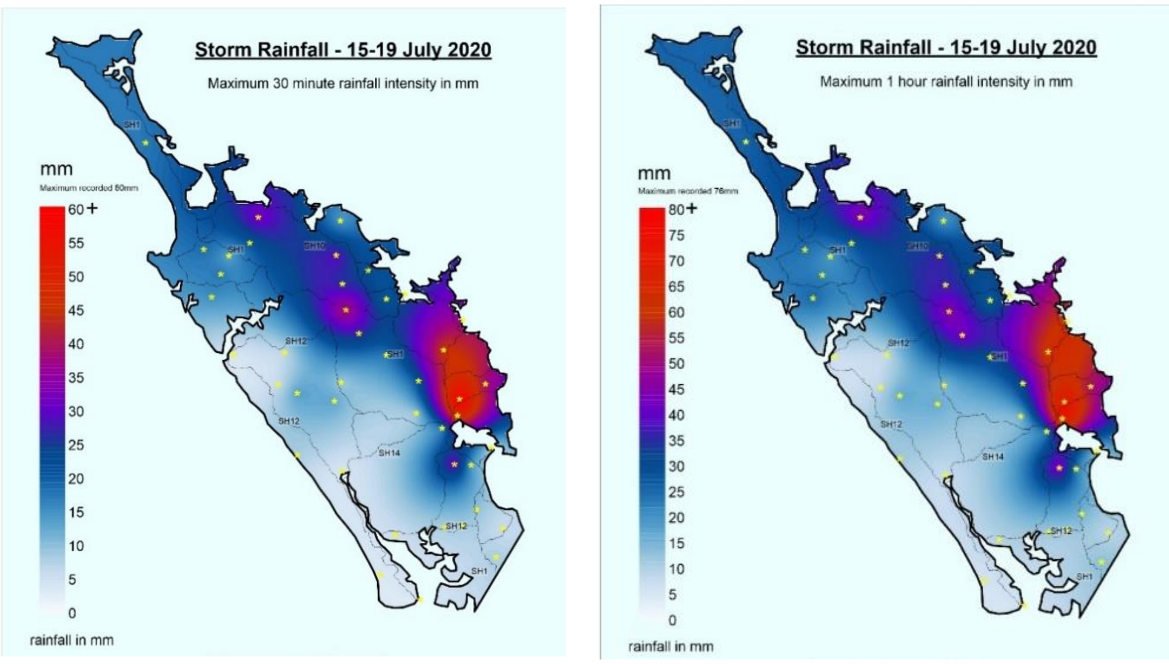


Figure 9: Maximum 30-minute and 1-hour rainfall intensity during the event across Northland.

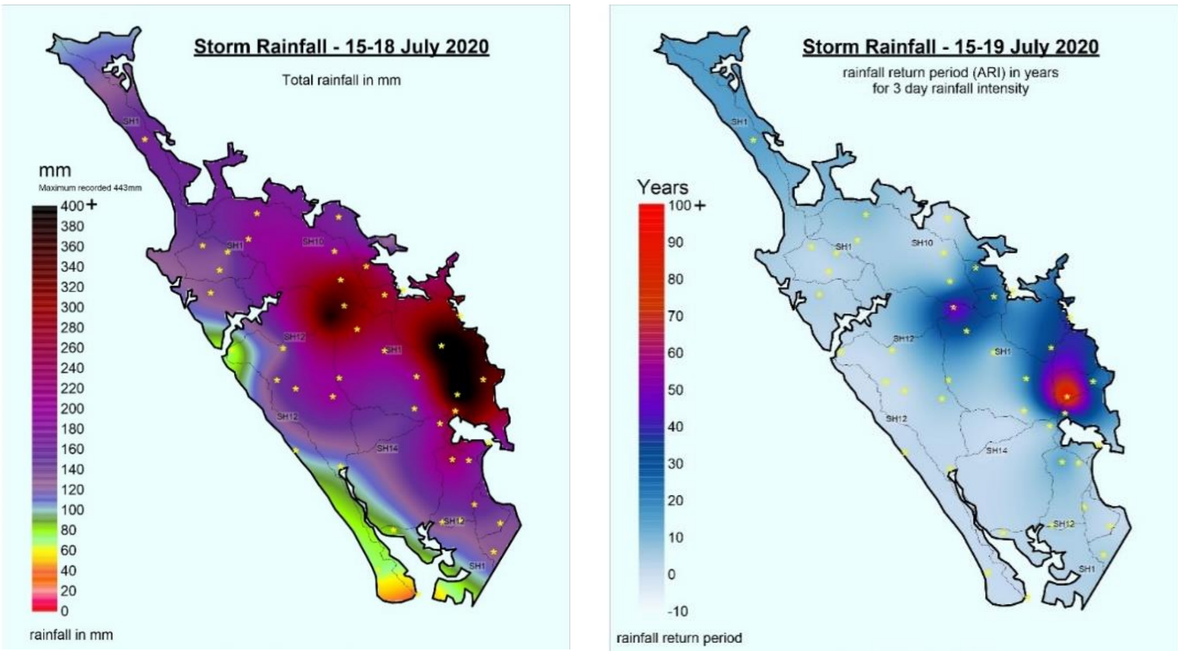


Figure 10: Total rainfall for the period 15-18 July 2020 (a) and the corresponding ARI map (b) across Northland region.

Flood

This section examines the 15-18 July 2020 flood by assessing:

- flood occurrence (includes triggering and timing of the flood, measured flood flows and the area affected by the flood).
- flood severity refers to either flood magnitude or flood frequency (i.e., how much water in the stream bed is flowing past a certain point or how often the flooding occurs in a given time period).

The severity of the July 2020 flood was also compared to other previous major flood events. For this assessment, the severity of July flood was expressed as peak flow return periods (T). The estimates were based on extreme value Type-1 and generalized extreme value distributions fitted to series of annual maxima of stream flows using L-Moment's (L-MOM) method.

Flood occurrence

Northland rivers responded quickly to the storm with rapid changes in flow discharge, causing multiple-peak flood event. The first peak discharge occurred early morning on 16 July, followed by a flood peak on 17 July evening or 18 July morning depending on catchment conditions (Figure 11). This quick response was a result of both antecedent catchment conditions (well saturated soil), and size of the storm event (extremely intense rainfall).

River water peaked at midnight on 17 July 2020 with highest flows were recorded in Whangārei and Bay of Islands areas.

- Whangārei had flood peak at 531 m^3/s (river water level of 10.71 m) at 21:40:00 in the Hātea River, 112 m^3/s (5.082 m) at 21:00:00 in the Waiarohia River. These are the highest flows on record since 1986. However, the flood peak at Whareora station in Hātea river was far higher than estimated flood peak (300 m^3/s) [(*)]. This difference could be due to tidal effect (Appendix 8). Therefore, the flood peak in Hātea at at Whareora station should be between 300 m^3/s and 531 m^3/s.
- Peak flows were 651 m^3/s (6.763 m) at 22:35:00 in the Waitangi River. This is the second highest flow on record after the Mar 2007 flood flow and water level (694 m^3/s and 6.94 m).

Flooding was widespread in the east with more surface water areas emerged during the storm (i.e., Waitangi, Hikurangi, Wairua rivers), which were well captured on Sentinel-1 satellite images (Figure 12).

Flood severity

The magnitude of a flood event varied in its frequency of occurrence over time in an inverse power relationship. This mutual relationship was determined by a frequency plot which showed variation between maximum instantaneous stream discharge and flow recurrence in years. The expected difference between flood magnitudes or frequencies computed from short records and their long-term values increased with recurrence interval and decreased with the length of the record.

The flood-frequency graph for an individual gaging station represents the relation of past flood discharges to the frequencies at which they occurred. For this report, the frequency curves were drawn as the line of best fit, determined visually, with consideration for the limitations and peculiarities inherent in the data.

July 2020 flood severity followed storm rainfall pattern. This means rivers in eastern parts of Northland had high flows (Tables 3 & 4). This is also well demonstrated in spatial distribution of storm rainfall and flood severity in terms of ARIs (Figure 14):

- Majority (16 out of 30 river stations) had low return period floods of 1-in-10 year or less ($T \leq 10$ years), they were in Far North, Mid North and Western Northland rivers.
- Whangārei area had flood return period between 1-in-20 years and 1-in-50 years (20 years $<T < 50$ years).
- Medium return period floods (25 years $\leq T \leq 50$ years) were at 9 stations in Bay of Island and around Whangārei rivers.
- The Ruakaka and Ngunguru rivers also experienced high flows with 1-in-30 and 1-in-20-year return periods, respectively.
- In the Bay of Islands area, the Waitangi and Waiharakeke rivers had medium flows of 1-in-30-year return period.

Established flood events

Historic flood events selected for this assessment were March 2003, March/July 2007, January 2011, and July 2014. There was same number of affected areas caused by the July 2014 and July 2020 floods. The March 2007 and January 2011 were the worst events in Northland with the most areas being affected by floods (Figure 15).

The magnitude and frequency of floods in individual catchment varied in those flood years. The most affected areas were Waiharakere, Ruakaka, Waitangi and Whangārei with high frequency of reoccurrence of a flood. Note, this was based on information given in Table 4 as an indication.

Northland flood occurrence during 2014-2019 can be visualised in Appendix 12. This is dirived from sattelite-based analyses.

(*) Flood peak was estimated using Rational method using design rainfall and key catchment and its river channel attributes; Q = F C I A where Q is peak discharge (m^3/s), F is unit conversion factor, C is dimensionless runoff coefficient, rainfall intensity during the design storm of duration (D) for the appropriate design annual exceedance probability (AEP) (mm/hr), and A is catchment area.

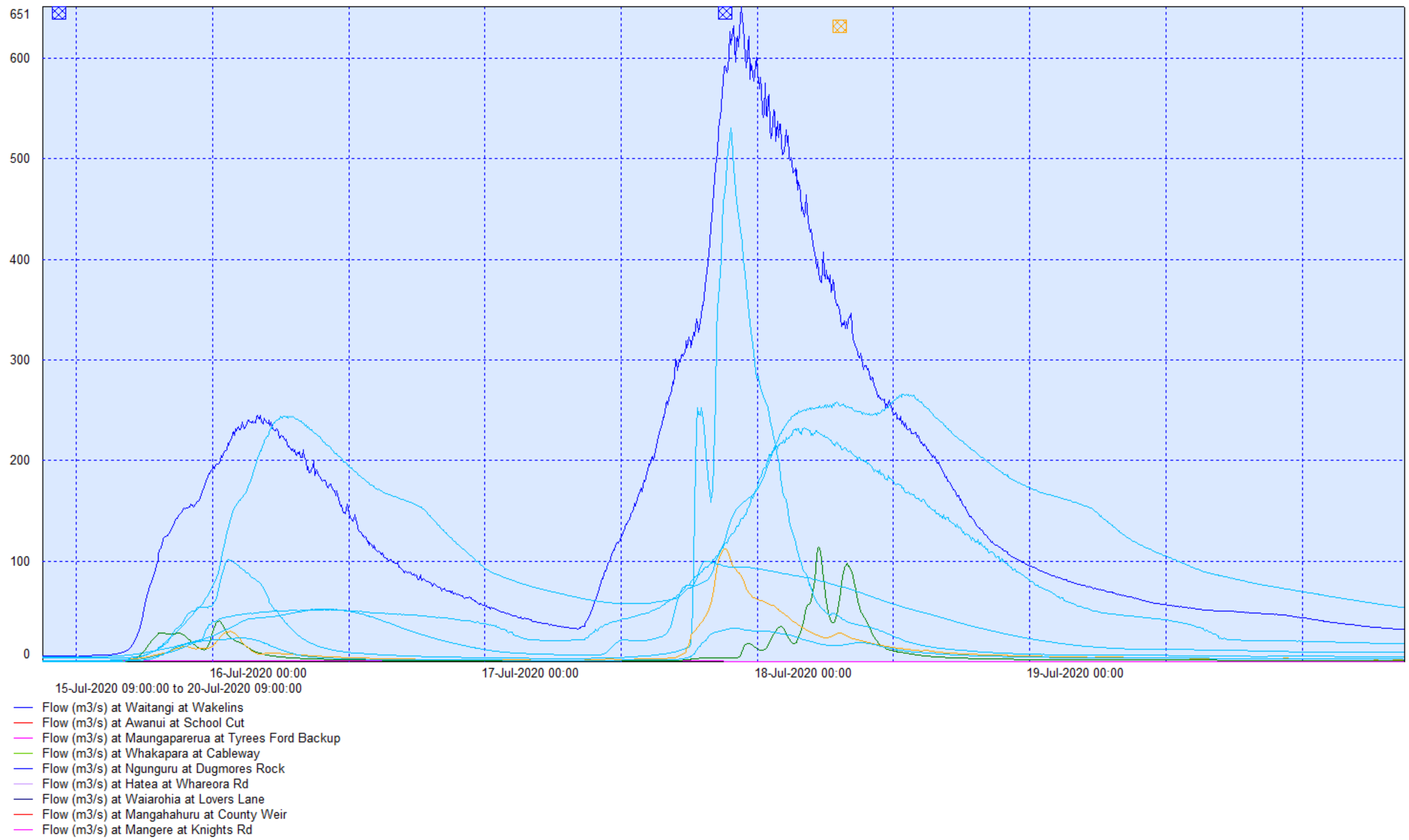


Figure 11: Discharge hydrographs for selected rivers during the 15 -19 July 2020 storm flood.

(Comments on data can be found in the little boxes that can be accessed from Hilltop).

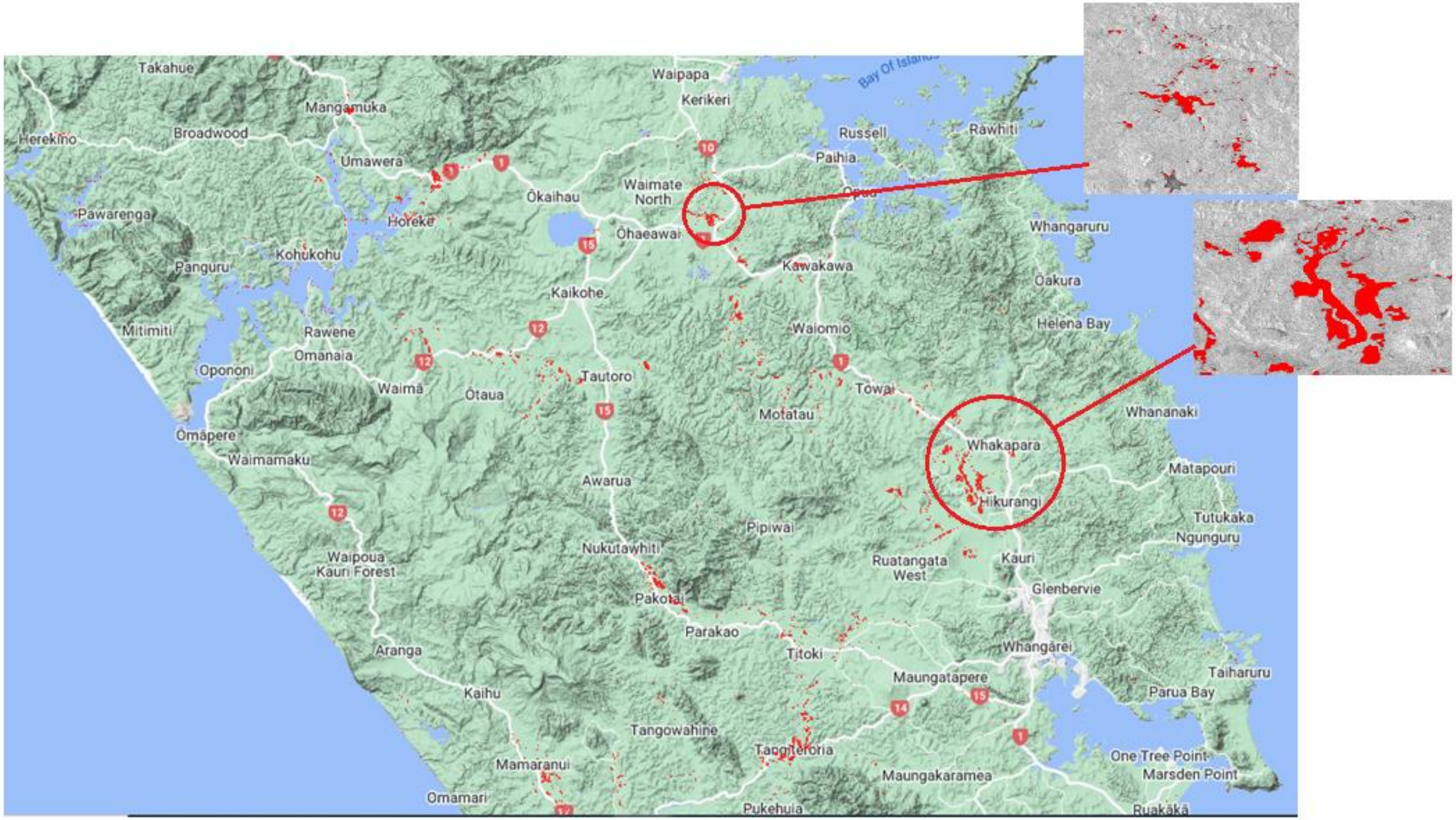


Figure 12: Flooded areas (in red) captured by Sentinel-1 satellite on 17 July 2020 (Source: floods · Wiki · EnviroSatTools / Documentation · GitLab).

Table 4: Frequency analysis of flood flows, between 15 and 18 July 2020 for selected stations.

Flow station	Start year	Catchment Area (km^2)	Peak flow (m^3/s)	Return period (years)
Awanui at School Cut	1958	222	233	11
Kaeo at Waiare Road	2008	72	114	2
Waitangi at Wakelins	1979	302	651	31
Waiharakeke at Willowbank	1967	229	215	28
Kaihu at Gorge	1970	609	119	2
Wairua at Wairua Bridge	1961	707	438	21
Ngunguru at Dugmores Rock	1969	12.5	114	14
Whakapara at Cableway	1959	162	265	6
Hātea at Whareora Road	1986	39	531	42
Waiarohia at Lovers Lane	1979	18.6	112	55
Raumanga at Bernard Street (*)	1979	64	81	21
Ruakaka at Flyger Road	1984	45	135	32
Waihoihoi at St Mary Rd	1984	57	25	3

Note: at this station (*) regulated high flows by the Hopua te Nihotetea (Kuruku) dam

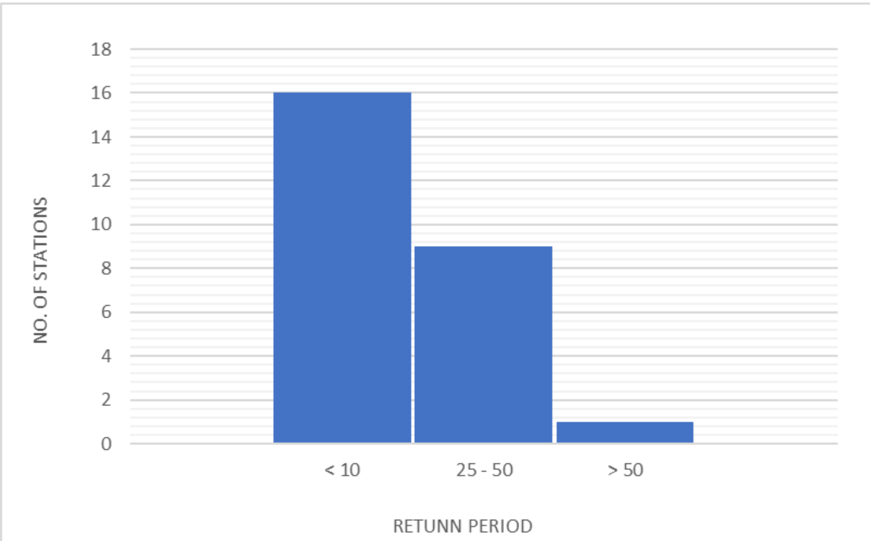


Figure 13: Number of flow stations associated with a range of return periods for the July 2020 flood.

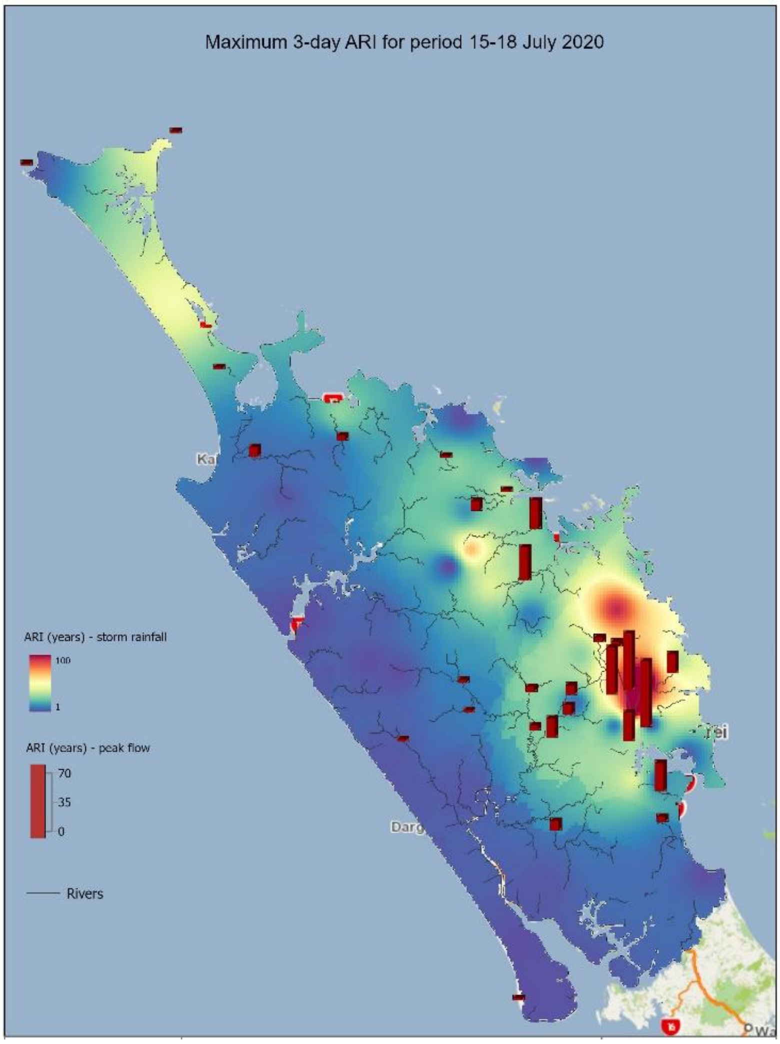


Figure 14: Severity of 15-18 July 2020 storm flood (in return periods).

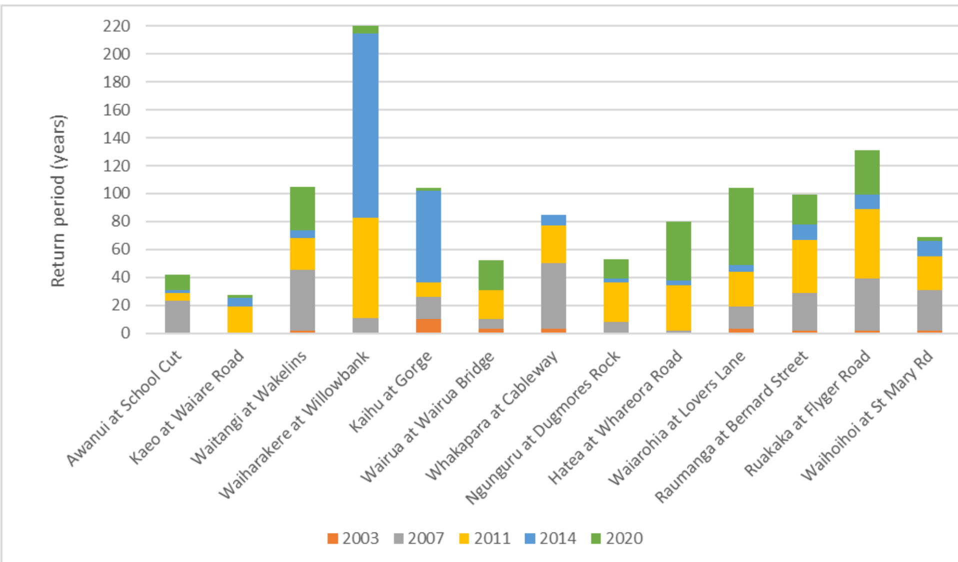


Figure 15: Flood occurrence: severity of the flood and its affected areas.

Whangārei Flood

Flood flows in three main rivers, Hātea, Waiarohia, and Raumanga, had significant contributions to flooding in Whangārei CBD during the storm. The July 2020 flows were the highest flows in the Hātea river since 1986, and in the Waiarohia River the highest since 1979 and what would have been the highest flow in the Raumanga River were it not for the Hopua te Nihotetea dam. Storm rainfall-flow relationships in these rivers during the event are presented in Figure 16.

The Whangārei area had highest peak flow return periods, with the Waiarohia, Hātea and Mangaharuru rivers flows between 1-in-20-year and 1-in-50-year return periods. Raumanga river had flow of 1-in-25 years return period or greater. For Raumanga, rainfalls were high during the event, but flows were much less than would have been expected without the operation of Hopua te Nihotetea dam (Table 4).

According to Riley (2020) the dam reduced the peak flows within the Raumanga Stream at the dam site from 36.9 m^3/s to 14.6 m^3/s, a reduction of 22.3 m^3/s. The peak flow for the storm event within the Raumanga Stream at Bernard Street, downstream of the dam, was 82.3 m^3/s. It is anticipated that for this storm event without the detention dam the flows within the Raumanga Stream at Bernard Street would have exceeded 100 m^3/s. The detention dam reduced the peak flows within the Raumanga Stream through the Whangārei CBD by approximately 20%, significantly reducing the severity of the flooding (Appendix 14).

Note, dam Inflows and outflows were modelled from rainfall in Otaika at Cemetery Road using Hydrologic Modeling System (HEC-HMS) model. The July event falls between a 2-year and 5-year ARI for 24-hour storm, and between 5 to 10-year ARI for 72-hour storm based on Riley's study.

These ARI estimates are slightly different from Council's estimates of 8 and 12 years return periods for 1-day and 3-day storm. It is envisaged that the methods used for estimation by both parties are not the same.

The extent of July 2020 flood was not modelled for Whangārei, but flood levels and its affected areas were compared with past flood events. In comparison to the established historic events, flood levels and flooded areas during the July event are likely to be insignificant. However, this is just an indication due to the lack of information and data.

> Flooded areas on 17 July 2020 were compared to the modelled flood extent (at 10 year-return period) (Figures 18) . The earlier was based on Senitel-1 satellite analyses by GNS as an example of Envirolink Tools for NZ regional councils. The latter was modelled flood extent developed by Water technology for the Council that were calibrated against historic events, especially Jan 2011 event for Whangārei River flood model.
>
> Flood levels during July 2020 and Jan 2011 at several locations in Whangārei were presented in Appendix 11.

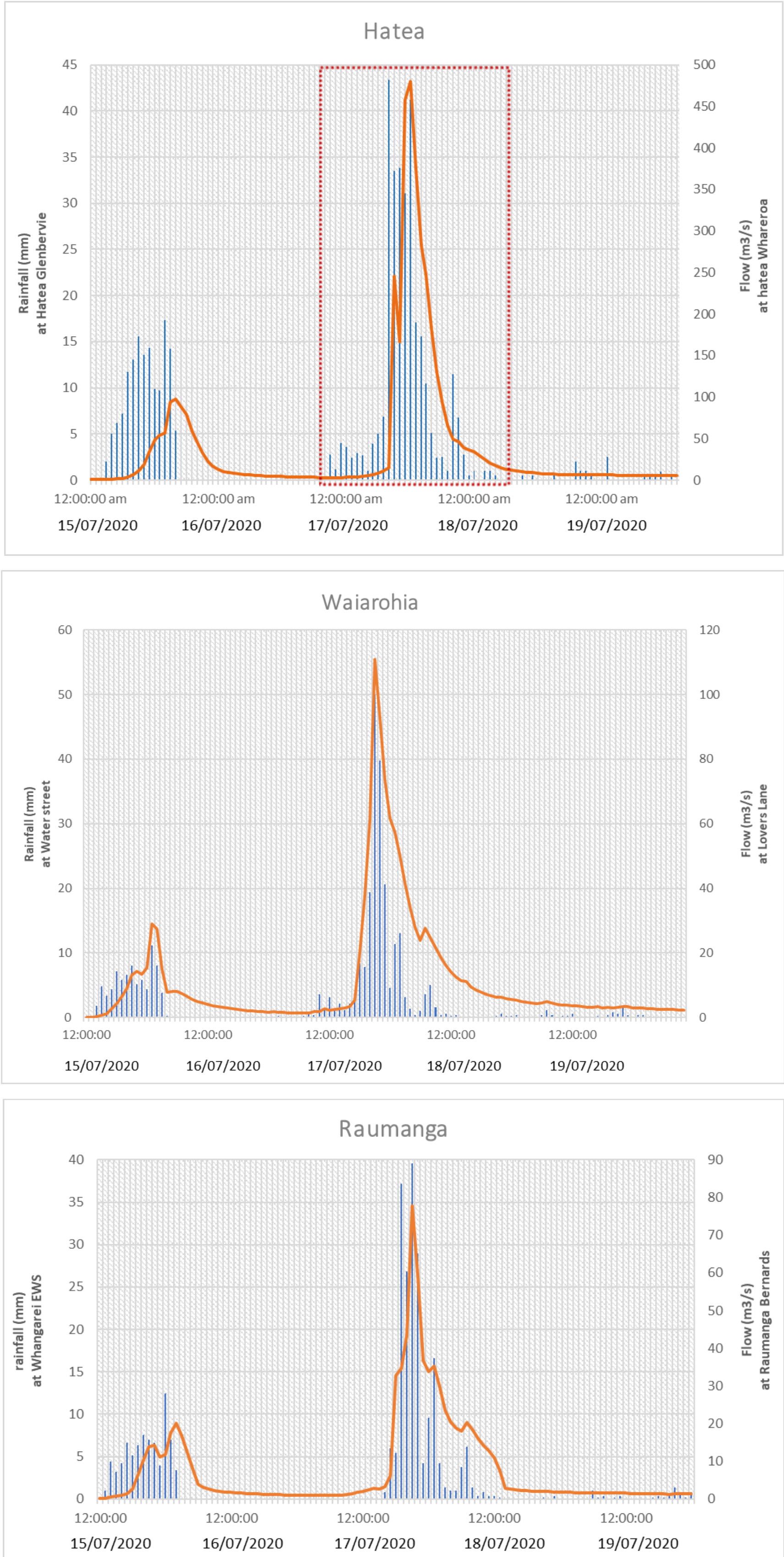


Figure 16: Hyetograph (blue) and discharge hydrograph (orange) for Hātea during the 15 -18 July 2020 storm flood.

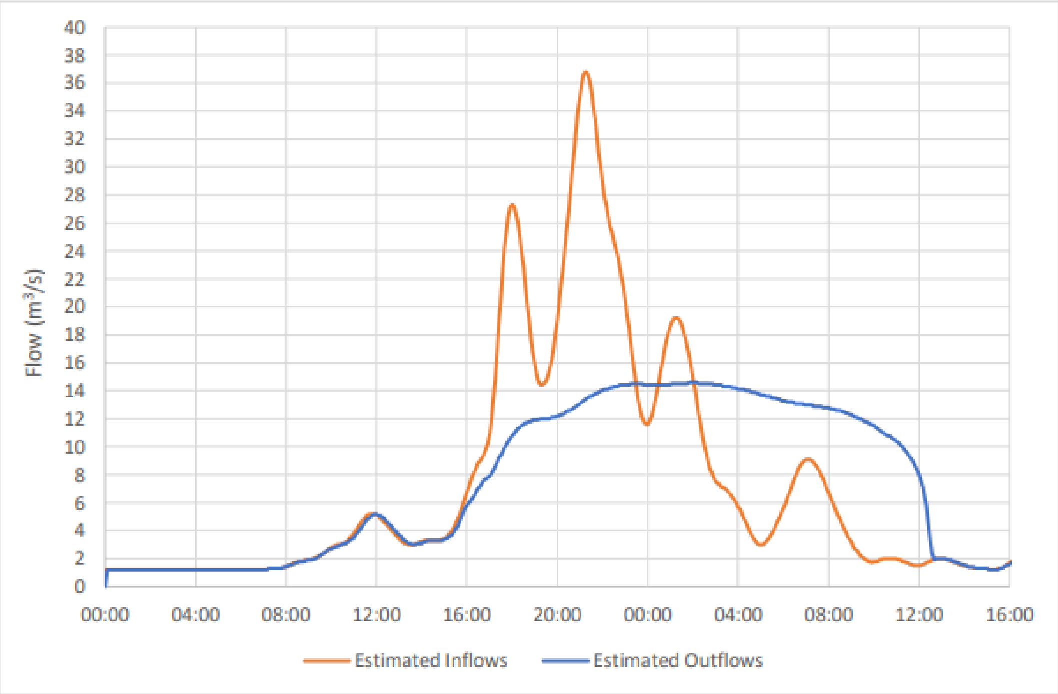


Figure 17: Modelled dam inflows and outflows for the July 2020 storm event (Riley, 2020).

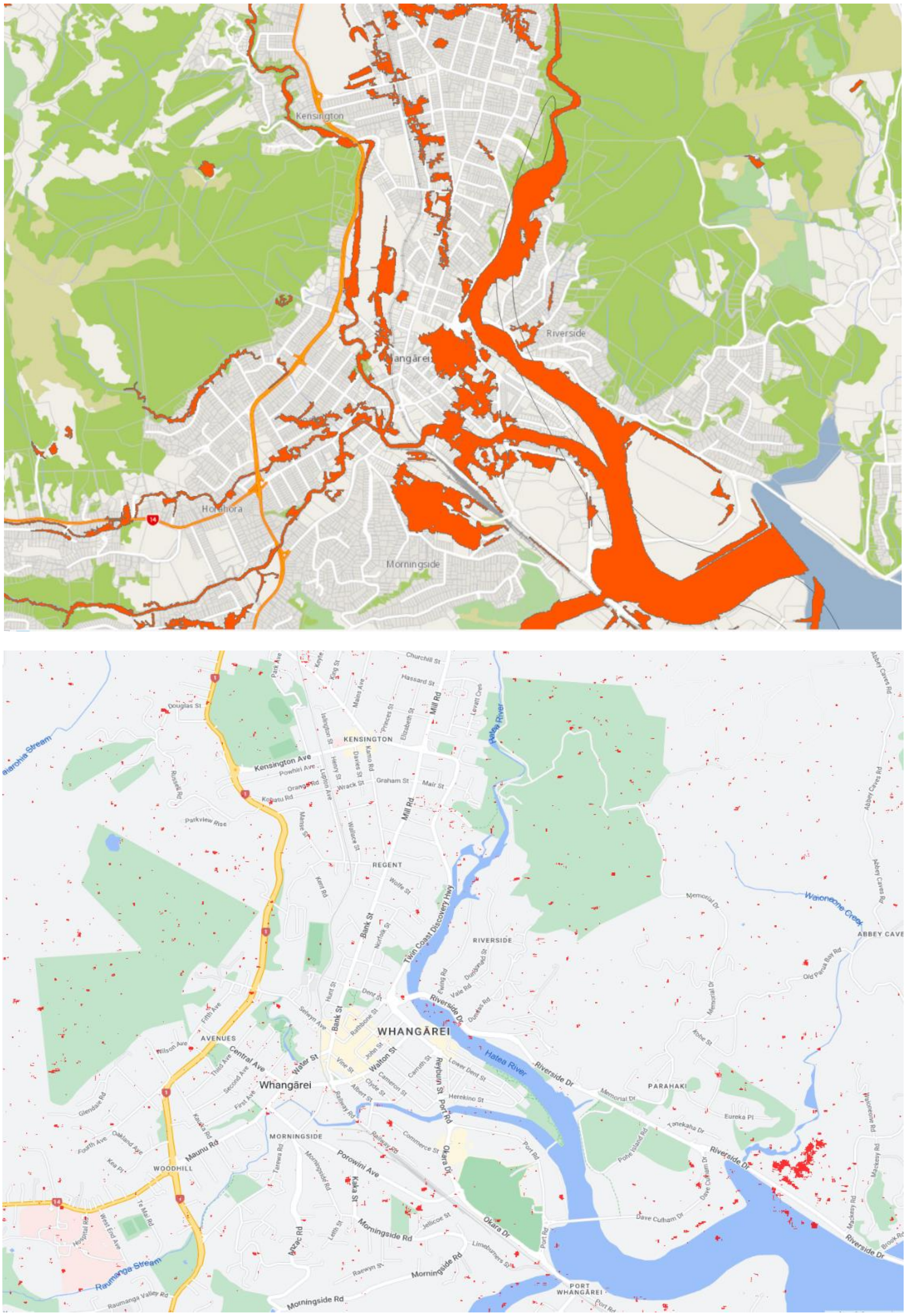


Figure 18: Comparison between Regional modelled flood extent (10-year return period) and flood areas captured by Sentinel-1 satellite (17 July 2020) for Whangārei. Note, flooded areas are shown in red colour.

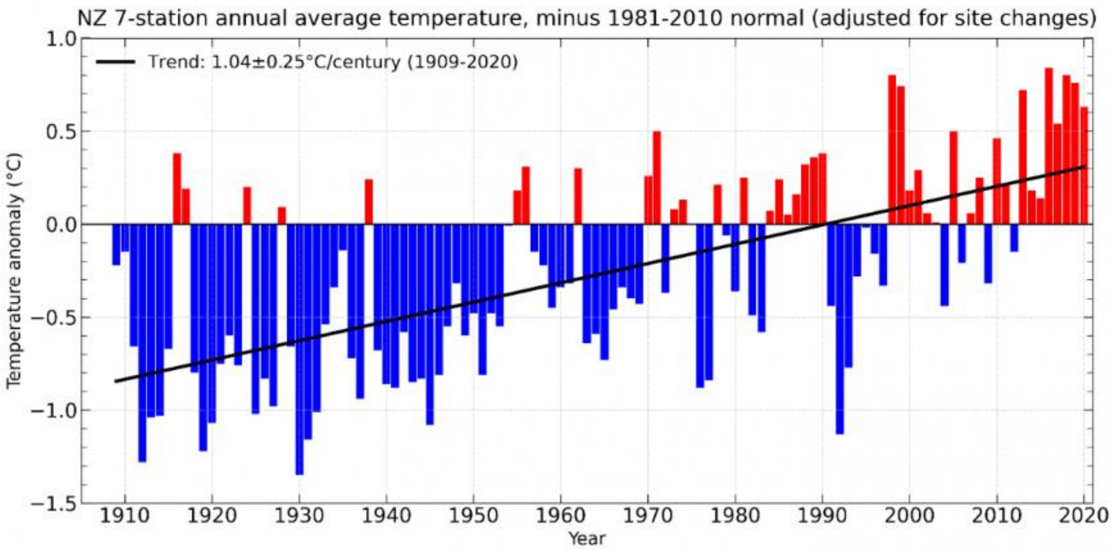
Long term variability

According to NIWA (2021), the year 2020 was New Zealand's seventh-warmest year on record, based on NIWA's seven-station series, which began in 1909 (Figure 19). New Zealand observed its warmest winter on record because of abnormally warm temperatures.

The Southern Annular Mode (SAM), a ring of Southern Hemisphere climate variability, was positive 61% of the time during 2020. Less than 40% of the time SAM was negative and fell in winter (Figure 20). The negative SAM phase is associated with low air pressure around New Zealand, which tends to cause more frequent westerly winds, unsettled weather, and storm activity over most of the country.

Prior to the July 2020 flood, Northland had experienced 24-month dryness because of abnormally warm temperature (Figure 21; Pham et al., 2022). This was alongside a near-record positive Indian Ocean Dipole (IOD), which persisted from late-2019 into early-2020, preventing atmospheric rivers (ARs)[*] from forming north of the country. ARs are an important moisture source for New Zealand, but these were non-existent over the country in late-summer and early-autumn (NIWA, 2020). In theory, a warmer atmosphere can hold more water vapour. Northland had been warm and dry for a long period. It is likely that New Zealand, and in particular Northland could had received more intense ARs when the tropical weather fronts passed the region on 15 July 2020. However, this hypothesis needs to be further investigated.

[*] ARs produce many heavy and extreme rainfall and flooding in New Zealand which usually come with weather fronts or cyclones and identically driven by SAM and Madden-Julian Oscillation (MJO) patterns. The mode of climate variability can alter seasonally and regional ARs, peak atmospheric river activity during summer and lowest atmospheric river activity during winter. Special cases may occur when ARs encounter mountainous terrain, it releases vast amount of water vapour falling as heavy rain or snow through orographic uplift (Kenett D., 2021; Kimberley J R. et al., 2021; Hamish D. et al., 2021; Shu J. et al., 2021). A study conducted by Shu J. et al. (2021) shows that, AR storms produce more than two times more daily rainfall than non-AR storms at most rainfall weather stations, and significantly more than three times for the west side of mountainous areas and northern New Zealand. Depending on the season in these areas, 40% to 86% of rainfall totals and 50% to 98% of extreme rainfall events are shown to be associated with atmospheric rivers. Similar findings are also revealed by Kenett D. (2021). For northern and western regions, over 45% of rainfall fell directly under AR conditions, contributing to daily rainfall totals 2.5 times higher on average compared to non-AR days. Further, AR days were associated with up to 70% of daily rainfall totals above the 99th percentile.



Historical nation-wide annual temperature anomalies (degrees above or below the 1981-2010 normal) from NIWA's seven-station temperature series which begins in 1909. Six of the past eight years have been among New Zealand's warmest on record.

Figure 19: New Zealand annual temperature anomalies (1909 – 2020).

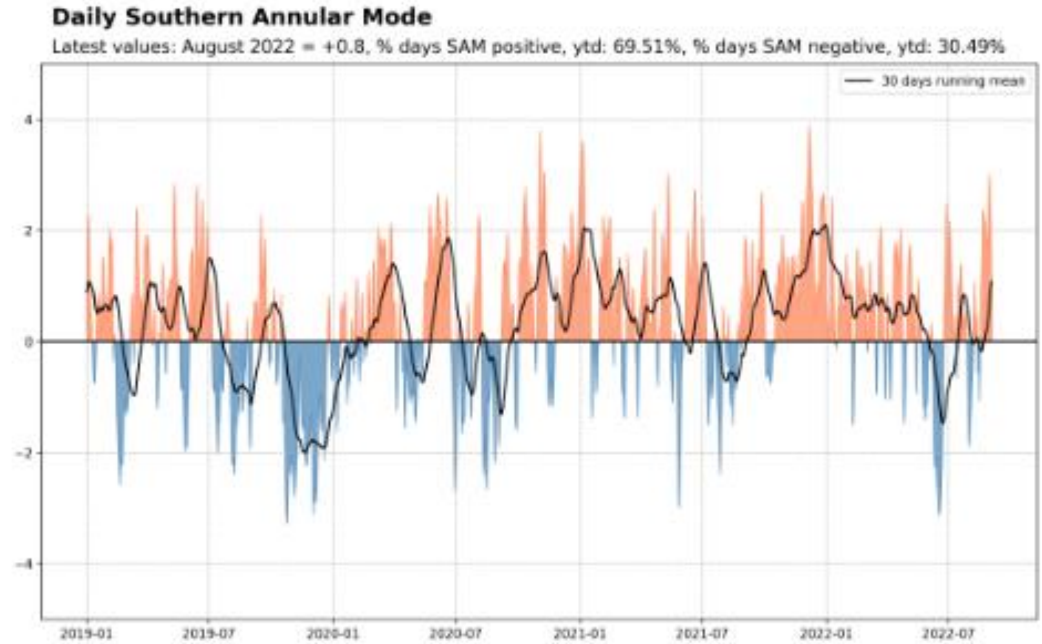


Figure 20: Daily average southern annular mode index (Source: National Centers for Environmental Prediction).

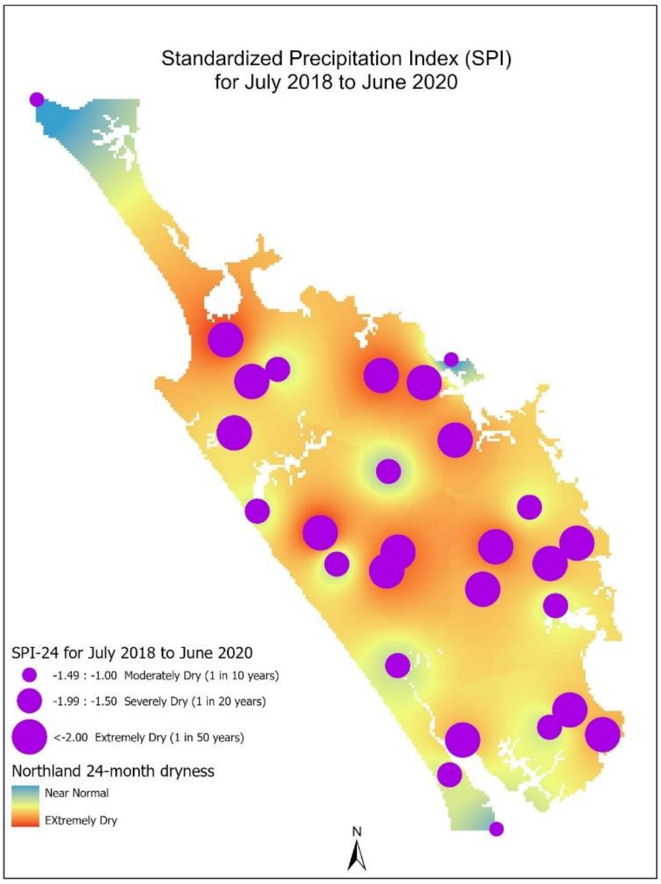


Figure 21: SPI-24 for July 2018 to June 2020.

Conclusions

The July 2020 storm was driven by an active trough moving southeast from the north Tasman Sea against a blocking zone of high pressure to the southeast of the country. The storm began on 15 July 2020 as a moderate event and later spread throughout Northland. This storm intensified on 17 July until 18 July 2020, mainly concentrating around Whangārei.

The July 2020 storm brought heavy rain and flooding in eastern parts of Northland. This was triggered largely by rainfall intensity than rainfall total. Most parts of Northland (exception for Hokianga and Pouto peninsula) received more than 100 mm during the storm event, but rainfall mainly intensified in Kaikohe, Waitangi, and Whangārei areas with over 100 mm fall in 6 hours. Notably, rainfall recorded at Kaikohe rain gauge exceeded 100-year ARIs for short periods, 30 minutes to 6 hours. Rainfall depth in these three areas promptly increased with increasing durations. Recorded rainfall over 3 days was highest in northern catchments of Whangārei of over 400 mm exceeding 100-year ARIs. This was followed by northern Kaikohe with highest rainfall on record (380 mm) exceeded 96-year ARIs. The Waitangi catchment received the third highest rainfall exceeding 50-year ARIs for 3-days. During the event, Council's rainfall network detected only one severe storm rainfall in Whangārei area while the weather rain radar captured two severe storm rainfalls, northern Kaikohe and Whangarei areas. The discovery by rain radar was confirmed throughout this assessment when using observed data from all organizations, Council, MET, NIWA (Appendix 6).

Northland rivers responded quickly to the storm rainfall; flood severity followed the rainfall intensity patterns. High floods occurred in several rivers on the eastern Northland, where;

- Whangārei area had highest flow on record which was likely driven by both highly intense rainfall and tidal flow. Therefore, Whangārei area's actual flood flow return period was between 1-in-25 years and 1-in-50 years. Likewise, Waitangi had medium flood return period between 25 years and 50 years (second highest flow on record).
- For Whangārei, peak flows within Raumanga stream through to CBD were significantly reduced by approximately 20% due to the operation of Hopua te Nihotetea retention dam.
- Among selected major historic flood events (March 2007, January 2011, July 2014), the March 2007 and January 2011 were the worst floods for Northland with the most areas being affected by floods, followed by the July 2014 and July 2020 floods with similarity in the high flow return periods and the numbers of affected areas.

The July 2020 flood was not preceded by high SPI but by very extreme short-term rainfalls (storm size) that caused the flood event. Another key influencing factor on flood severity was antecedent soil moisture (well saturated prior to the storm) that was clearly proved for Waitangi and Whangārei areas. NIWA (2007) suspected that Northland post-1999 years may be experiencing severe weather and floods with similar patterns to what the region experienced during 1947-1977. This was based on decadal-scale variations in El Niño Southern Oscillation patterns. Since 2007, Northland experienced several damaging floods, including January 2011, July 2014 and July 2020. The July 2020 storm pattern was relatively similar to March and July 2007 storm pattern. Compared to post-2007 floods, the July 2020 flood was less severe. However, more analyses are required to characterise the floods pre- and post-2007.

Northland's abnormal warm temperatures since June 2018 (when regional drought commenced), alongside with the activity of negative SAM phase in winter 2020 suggests more intense ARs to be formed over the region. This means heavier rainfalls could have landed in the region during 15–18 July 2020. However, this topic needs further investigation.

Other findings are as follows:

- Rain gauges are likely to have missed heavy rainfall in some locations. Critically, the most severe rainfall in Kaikohe was detected by rain radar but not by the Council rain gauges (Appendix 6).
- Satellite-derived flood maps clearly show the affected areas during the storm event (Figure 12 and Appendix 12).
- For some gauging stations, past flood events are samples recorded from a limited period of flood history, therefore, it would be presumptuous to expect the same relation to hold true in the future. This leads to the different estimation among studies results.

Limitation and Recommendations

Limitations

This flood assessment delivers key characteristics of July 2020 storm rainfall and flood which does not quantify the impacts of flooding (i.e., does not explicitly quantify the flood inundation depth and extent).

Recommendations

- Examination of trends and projections on the frequency and magnitude of extreme rainfalls and floods.
- Categorise and characterise Northland storms, extreme rainfall and resulting floods.
- Analyse the differences in the long-term regimes of extreme precipitation and floods to understand the main flood-producing processes (using seasonality indices and atmospheric circulation patterns). For example, cluster analyses to identify areas of similar flood processes, both in terms of precipitation forcing and catchment processes.
- Quantify the impacts of large-scale atmospheric variability (SAM, Ars, etc.) on extreme rainfalls and floods.
- Real-time ARIs, computed based on gauge-corrected radar-estimated rainfall maps/grids are highly recommended as rain radar has become available for Northland.
- Develop flood forecasting models using rain radar, satellite data, large-scale atmospheric processes for both short and seasonal scales.
- Modelling of flood inundation and mapping of flood extent.
- Data sharing between organizations during the flood event.

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Appendices

Appendix 1: Location (X, Y coordinates) of rain gauges (on-request).

Rainfall site	X	Y
North Cape		
Waihopo at Kimberley Road		
Oruru RG at Bowling Club		
Tarawhataroa at Larmer Road		
Takahue at Te Rore		
Takahue at Saddle Road		
Te Puhi at Mangakawakawa Trig		
Kaeo at Bramleys		
Touwai at Weta		
Kerikeri at BOI Golf Club		
Rotokakahi at Kohe Rd		
Waitangi at Ōhaeawai		
Waitangi at Wiroa Road		
Waitangi at McDonald Road		
Veronica Channel at Opua Wharf		
Otiria at Ngapipito		
Whawharu at Topu B Taheke		
Hokianga Harbour at Omapere/Opononi		
Waimamaku at Weka Weka Road		
Opouteke at Brookvale		
Mangakahia at Twin Bridges		
Oakura Bay at Te Kapua Street		
Waiharakeke RG at Okaroro Road		
Whakapara at Puhipuhi		
Okarika at Rowland Rd		
Hātea at Glenbervie Forest HQ		
Ngunguru at Dugmores Rock		
Waipao at Draffins Rd		
Waiarohia at Northland Regional Council Water St		
Otaika at Cemetery Road		
Whangārei Harbour at Marsden Point		
Waikokopa RG at McDonnell Road		
Waiwarawara Rain at Wilsons Dam		
Waihoihoi at Brynderwyn		
Waima at Tutamoe		
Kaiiwi at Kaiiwi Lakes		
Dargaville at Climate (NIWA)		
Awaroa at Wallace Road		
Hakaru at Tara		
Paparoa at Maungaturoto		

Rainfall site	X	Y
Paparoa at Taylors		
Okoraka at Ngatawhiti Road		
Kaipara Harbour at Pouto Point		
Hakaru at Topuni Creek Farm		
Warkworth		

Appendix 2: Location (X, Y coordinates) of flow stations (on-request).

Flow station	X	Y
Awanui at School Cut		
Waitangi at Wakelins		
Maungaparerua at Tyrees Ford		
Waiharakeke at Willowbank		
Whakapara at Cableway		
Ngunguru at Dugmores Rock		
Hātea at Whareora Road		
Waiarohia at Lovers Lane		
Raumanga at Bernard Street		
Ruakaka at Flyger Road		
Manganui at Permanent Station		
Wairua at Purua		
Wairua at Wairua Bridge		
Mangakahia at Gorge		
Selwyn Swamp at Big Flat Road		
Oruru at Saleyards		
Kaeo at Waiare Road		
Rangitane at Stirling		
Hikurangi at Moengawahine		
Mangakahia at Titoki		
Opouteke at Suspension Bridge		
Kaihu at Gorge		
North at Applecross		
Mangahahuru at County Weir		
Mangere at Knights Road		
Waiotu at SH1		

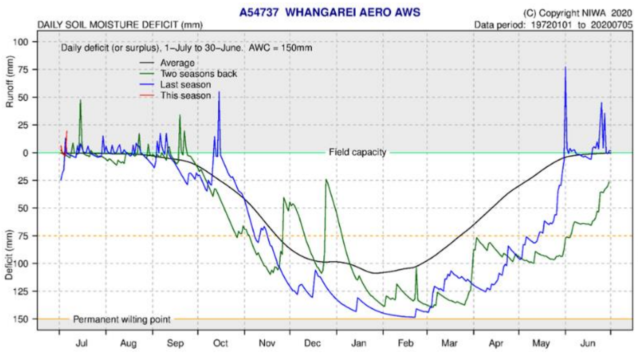
Appendix 3: Location (X, Y coordinates) of soil moisture stations (on-request).

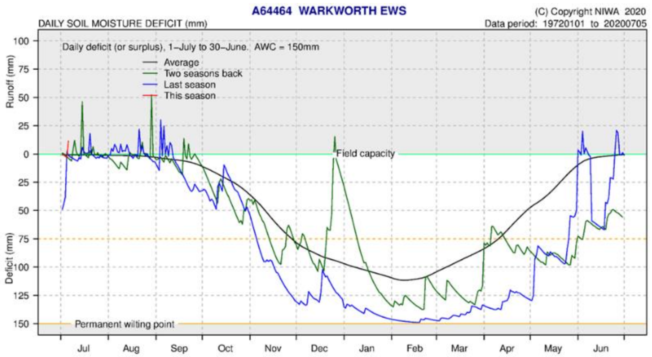
NIWA Climate Station	X	Y
Kaitaia		
Kerikeri		
Whangārei		
Kaikohe		
Dargaville		
Warkworth		

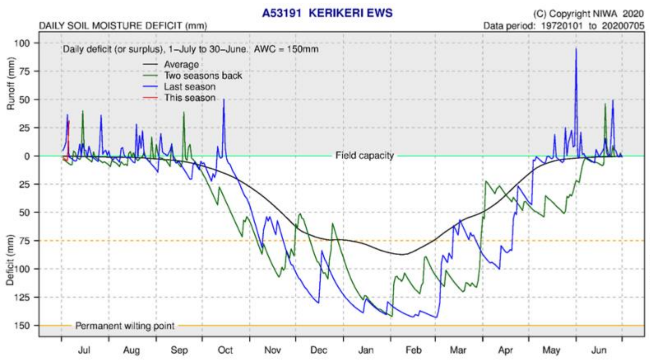
Note: SMD is calculated based on incoming daily rainfall (mm), outgoing daily potential evapotranspiration (PET, mm), and a fixed available water capacity (the amount of water in the soil 'reservoir' that plants can use) of 150 mm (NIWA).

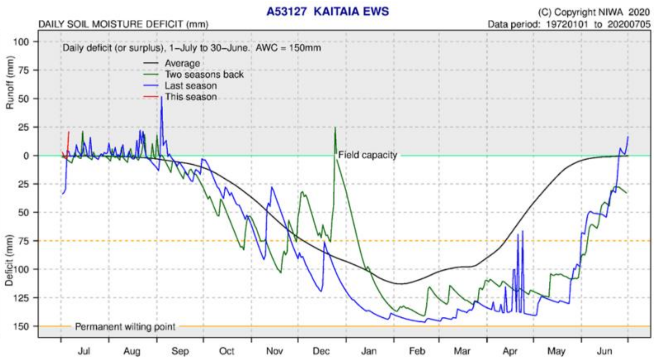
Appendix 4: Soil moisture.

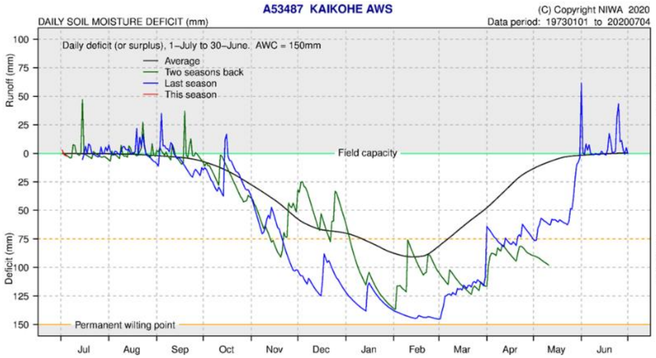
Appendix 4.1 - June 2020 Soil moisture:

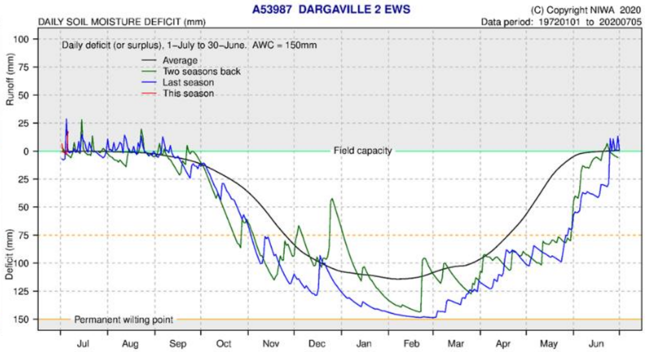




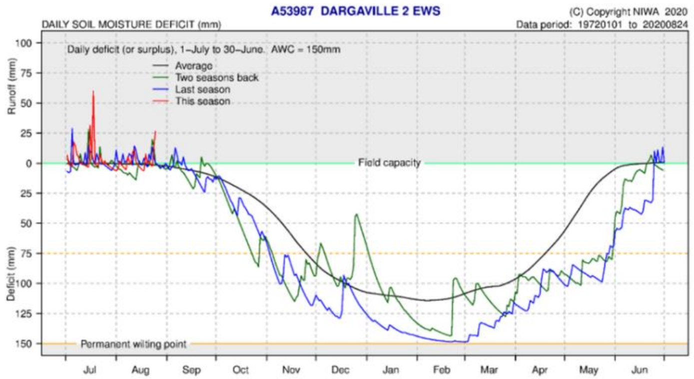


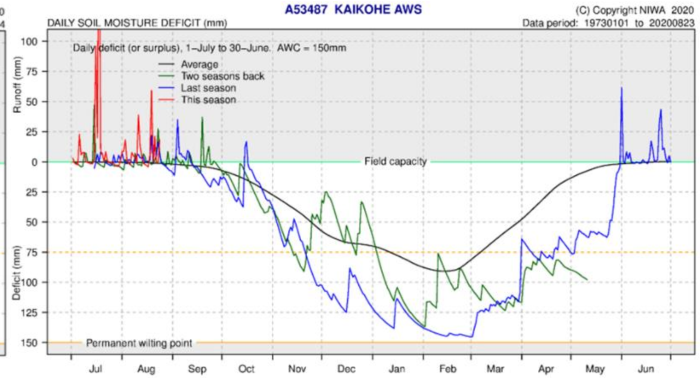


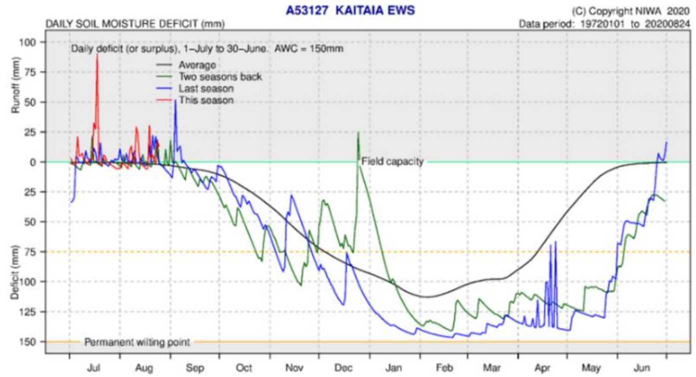


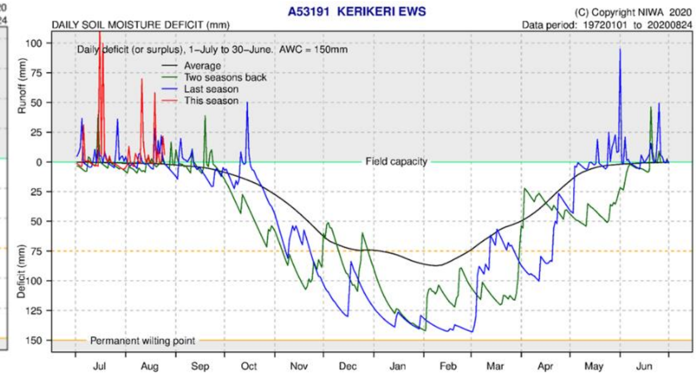


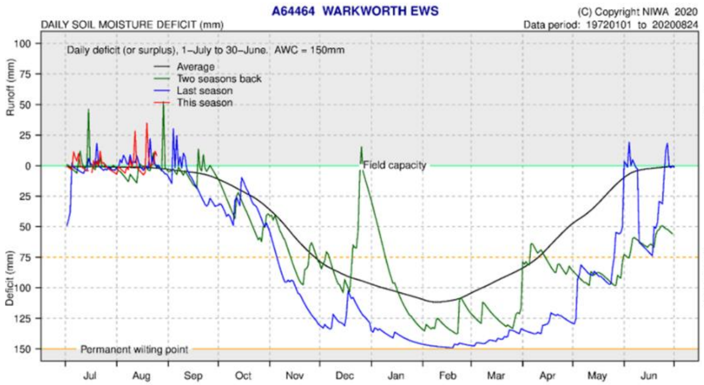
Appendix 4.2 - July – August 2020 Soil moisture:

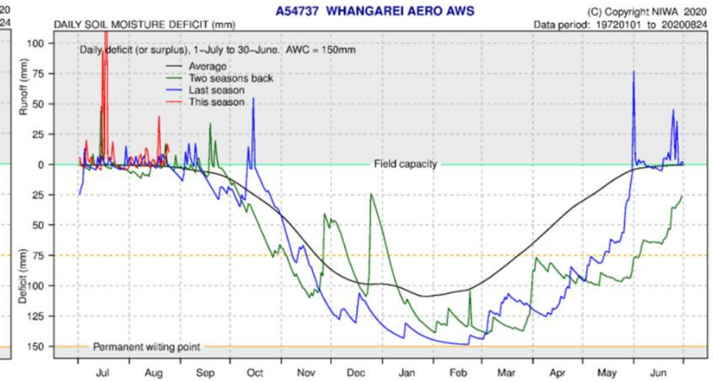

A53987 DARGAVILLE 2 EWS
DAILY SOIL MOISTURE DEFICIT (mm)
(C) Copyright NIWA 2020
Data period: 19720101 to 20200824
Daily deficit (or surplus), 1–July to 30–June. AWC = 150mm
Average
Two seasons back
Last season
This season
Field capacity
Permanent wilting point
Runoff (mm)
Deficit (mm)
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun


A53487 KAIKOHE AWS
DAILY SOIL MOISTURE DEFICIT (mm)
(C) Copyright NIWA 2020
Data period: 19730101 to 20200823
Daily deficit (or surplus), 1–July to 30–June. AWC = 150mm
Average
Two seasons back
Last season
This season
Field capacity
Permanent wilting point
Runoff (mm)
Deficit (mm)
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun


A53127 KAITAIA EWS
DAILY SOIL MOISTURE DEFICIT (mm)
(C) Copyright NIWA 2020
Data period: 19720101 to 20200824
Daily deficit (or surplus), 1–July to 30–June. AWC = 150mm
Average
Two seasons back
Last season
This season
Field capacity
Permanent wilting point
Runoff (mm)
Deficit (mm)
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun

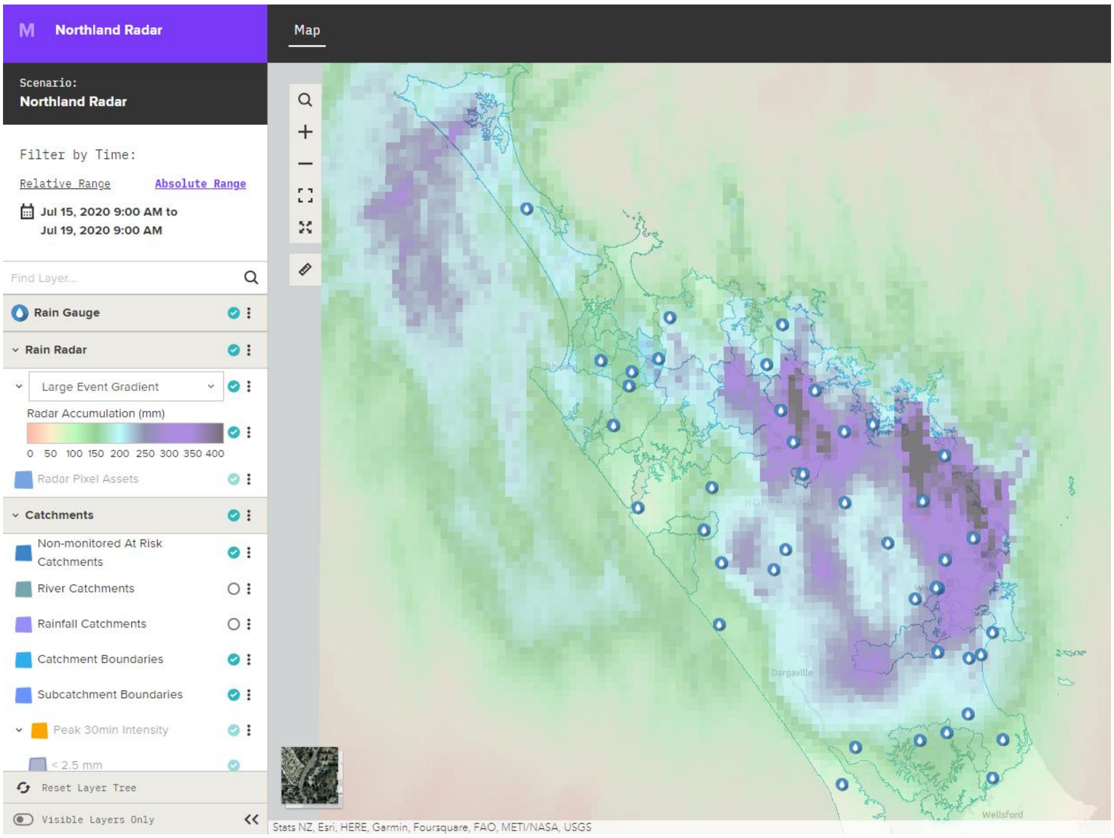

A53191 KERIKERI EWS
DAILY SOIL MOISTURE DEFICIT (mm)
(C) Copyright NIWA 2020
Data period: 19720101 to 20200824
Daily deficit (or surplus), 1–July to 30–June. AWC = 150mm
Average
Two seasons back
Last season
This season
Field capacity
Permanent wilting point
Runoff (mm)
Deficit (mm)
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun


A64464 WARKWORTH EWS
DAILY SOIL MOISTURE DEFICIT (mm)
(C) Copyright NIWA 2020
Data period: 19720101 to 20200824
Daily deficit (or surplus), 1–July to 30–June. AWC = 150mm
Average
Two seasons back
Last season
This season
Field capacity
Permanent wilting point
Runoff (mm)
Deficit (mm)
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun

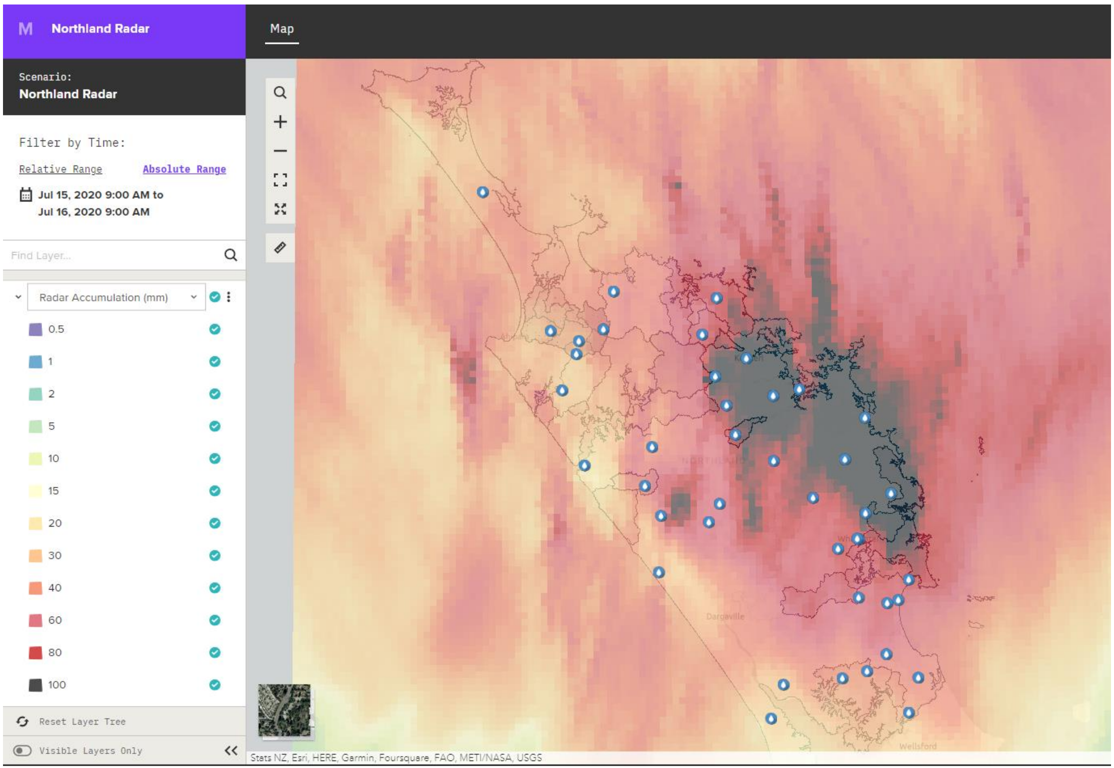

A54737 WHANGAREI AERO AWS
DAILY SOIL MOISTURE DEFICIT (mm)
(C) Copyright NIWA 2020
Data period: 19720101 to 20200824
Daily deficit (or surplus), 1–July to 30–June. AWC = 150mm
Average
Two seasons back
Last season
This season
Field capacity
Permanent wilting point
Runoff (mm)
Deficit (mm)
Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun

Appendix 5: Rain radar.

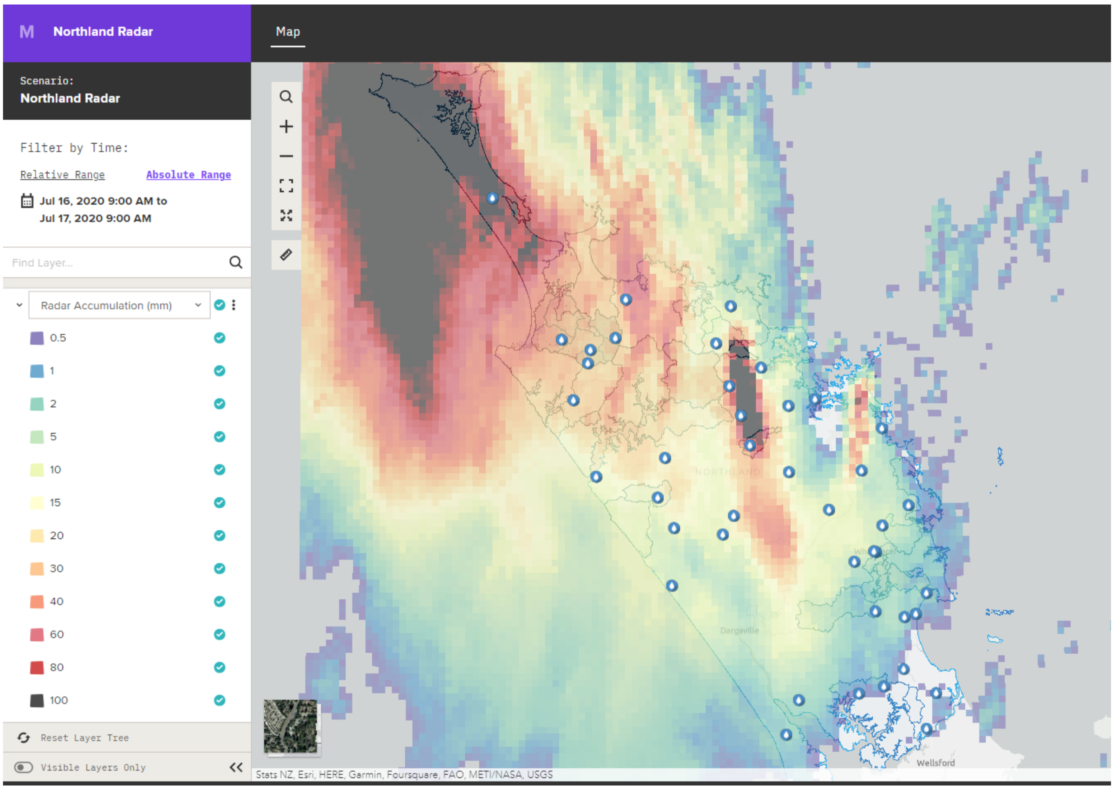
Appendix 5.1.1 - Rain radar: large event gradient



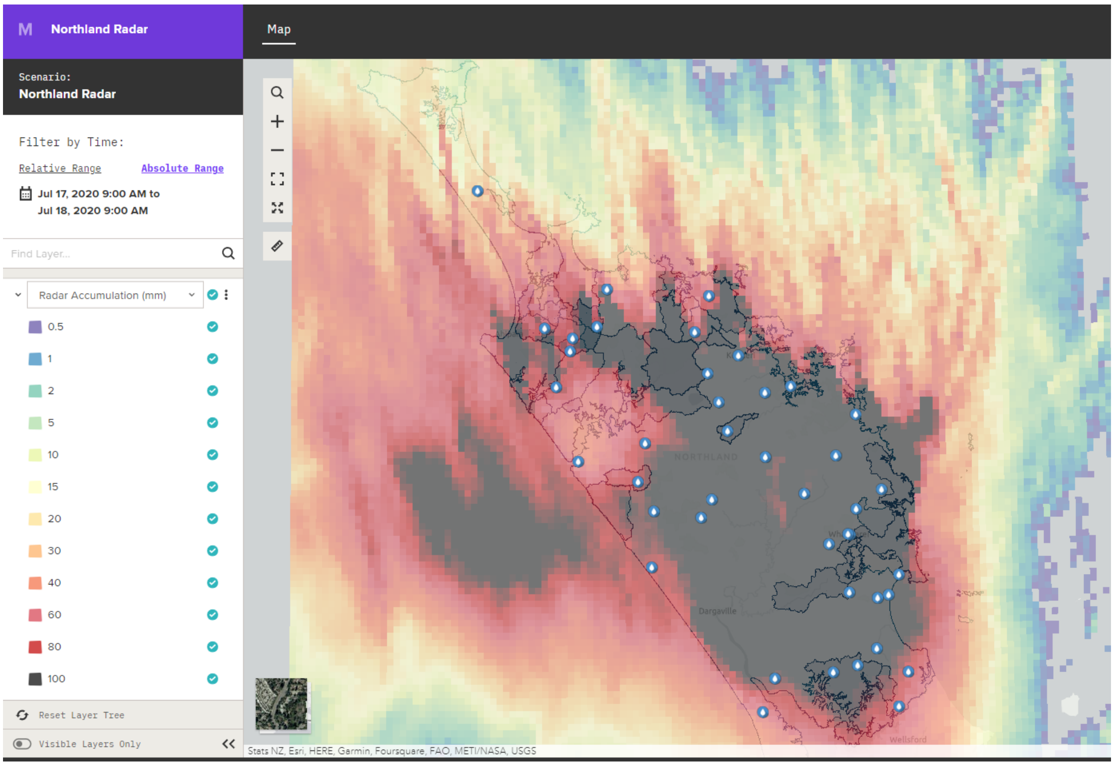
Appendix 5.1.2 - Rain radar: Radar Accumulation from 15 Jul to 16 Jul 2020



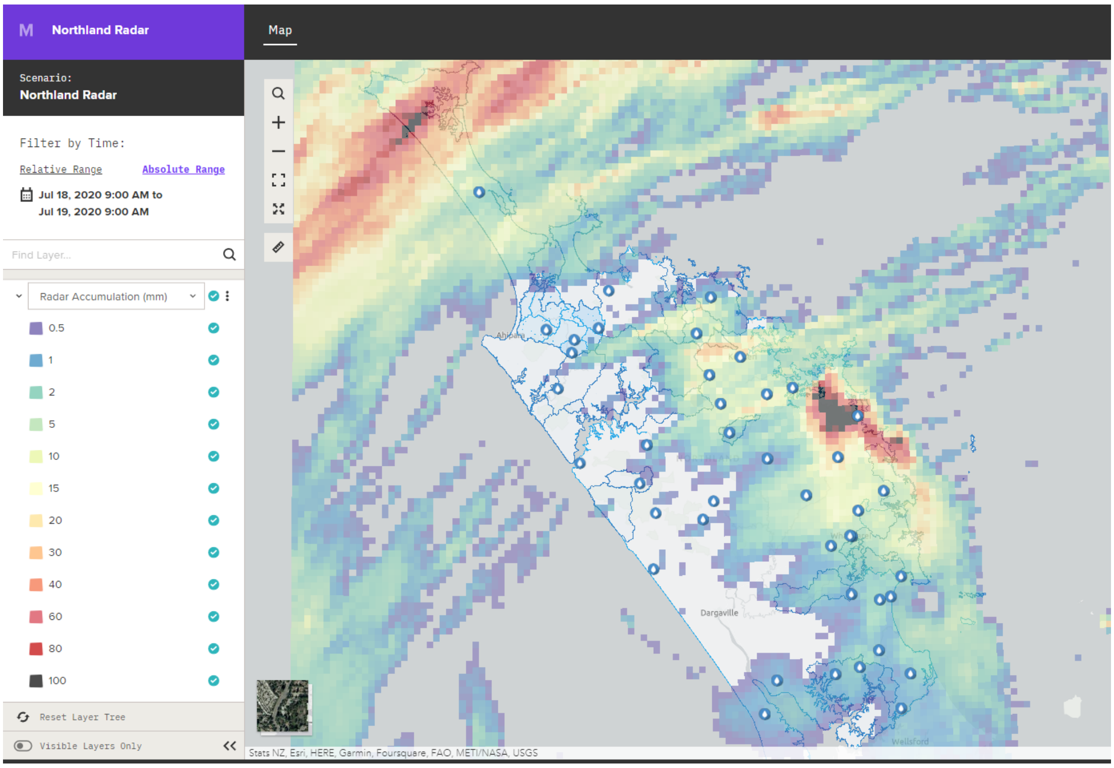
Appendix 5.1.3 - Rain radar: Radar Accumulation from 16 Jul to 17 Jul 2020



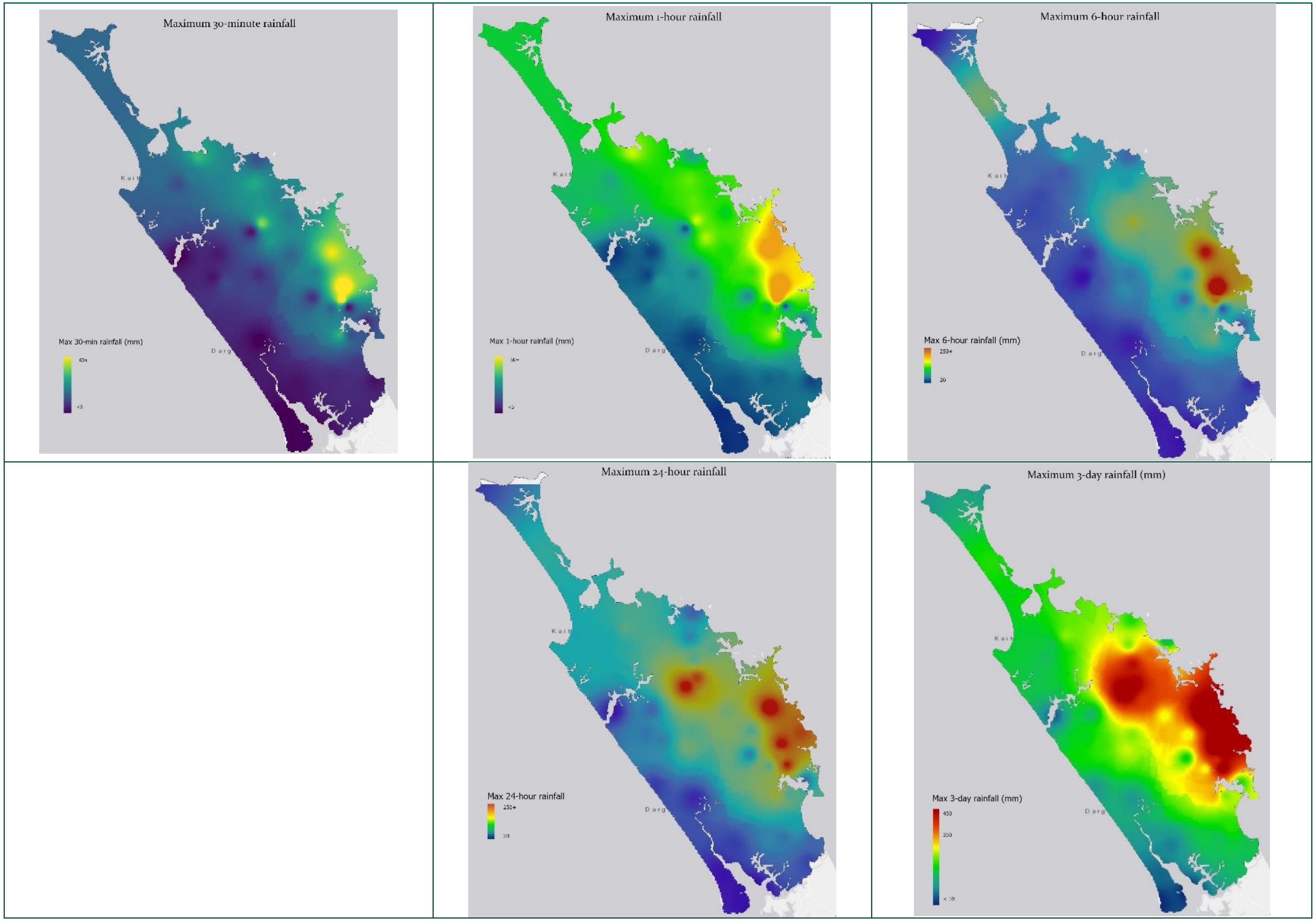
Appendix 5.1.4 - Rain radar: Radar Accumulation from 17 Jul to 18 Jul 2020



Appendix 5.1.5 - Rain radar: Radar Accumulation from 18 July to 19 July 2020

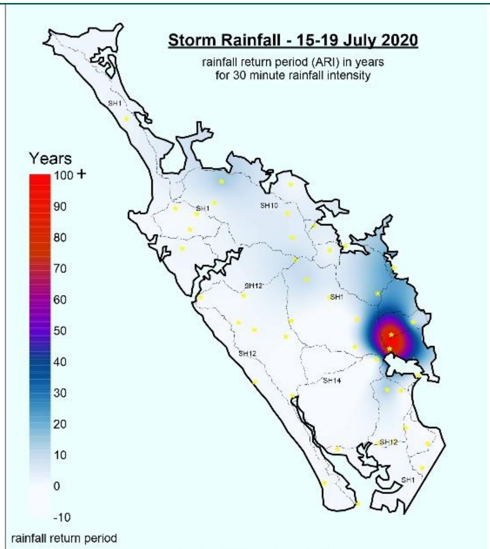


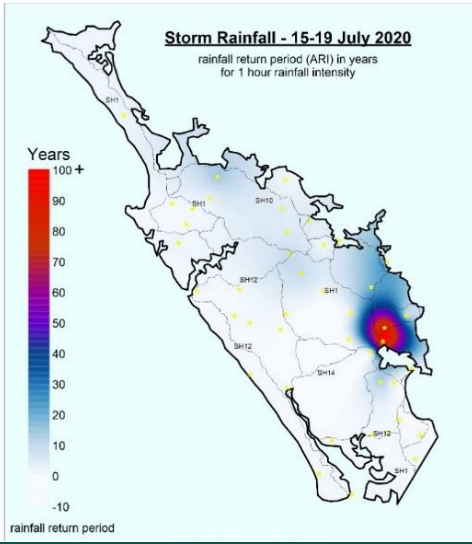
Appendix 5.2- Maximum storm intensity:

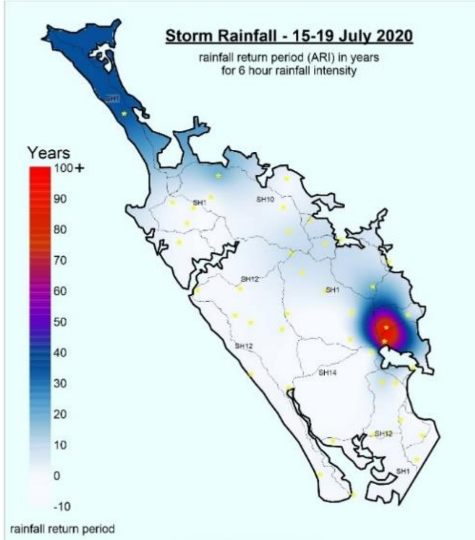


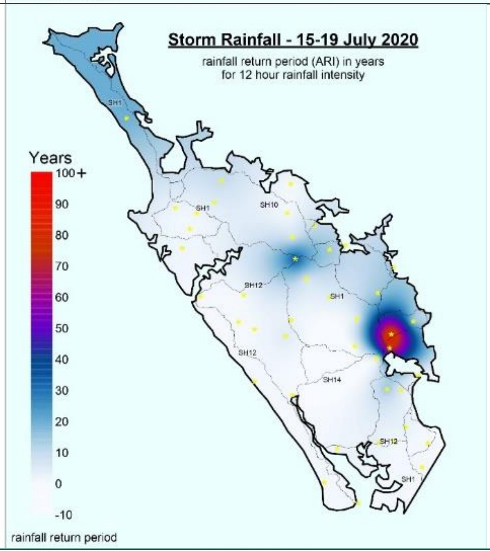
Appendix *6*:Storm return periods, maximum accumulation, and maximum rainfall intensity.

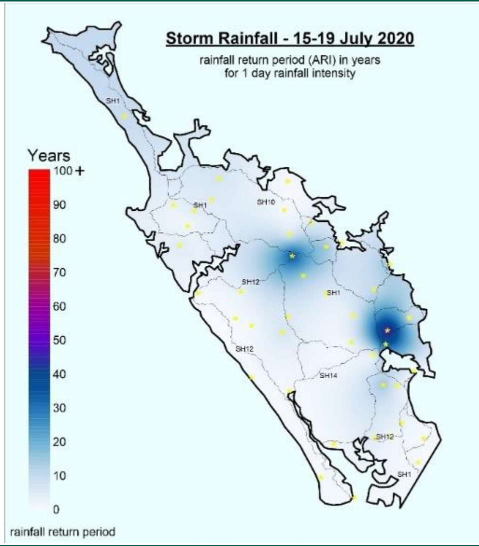
Appendix 6.1 - Storm return periods

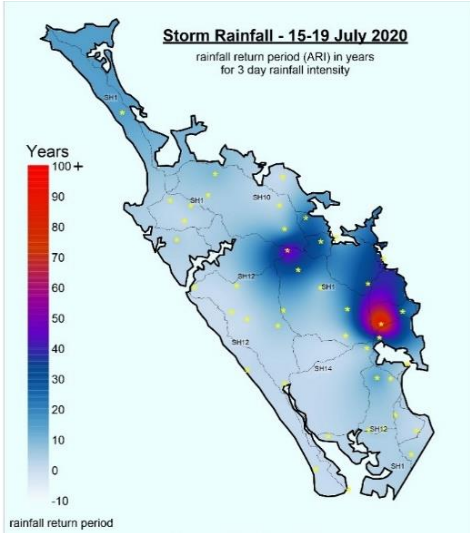




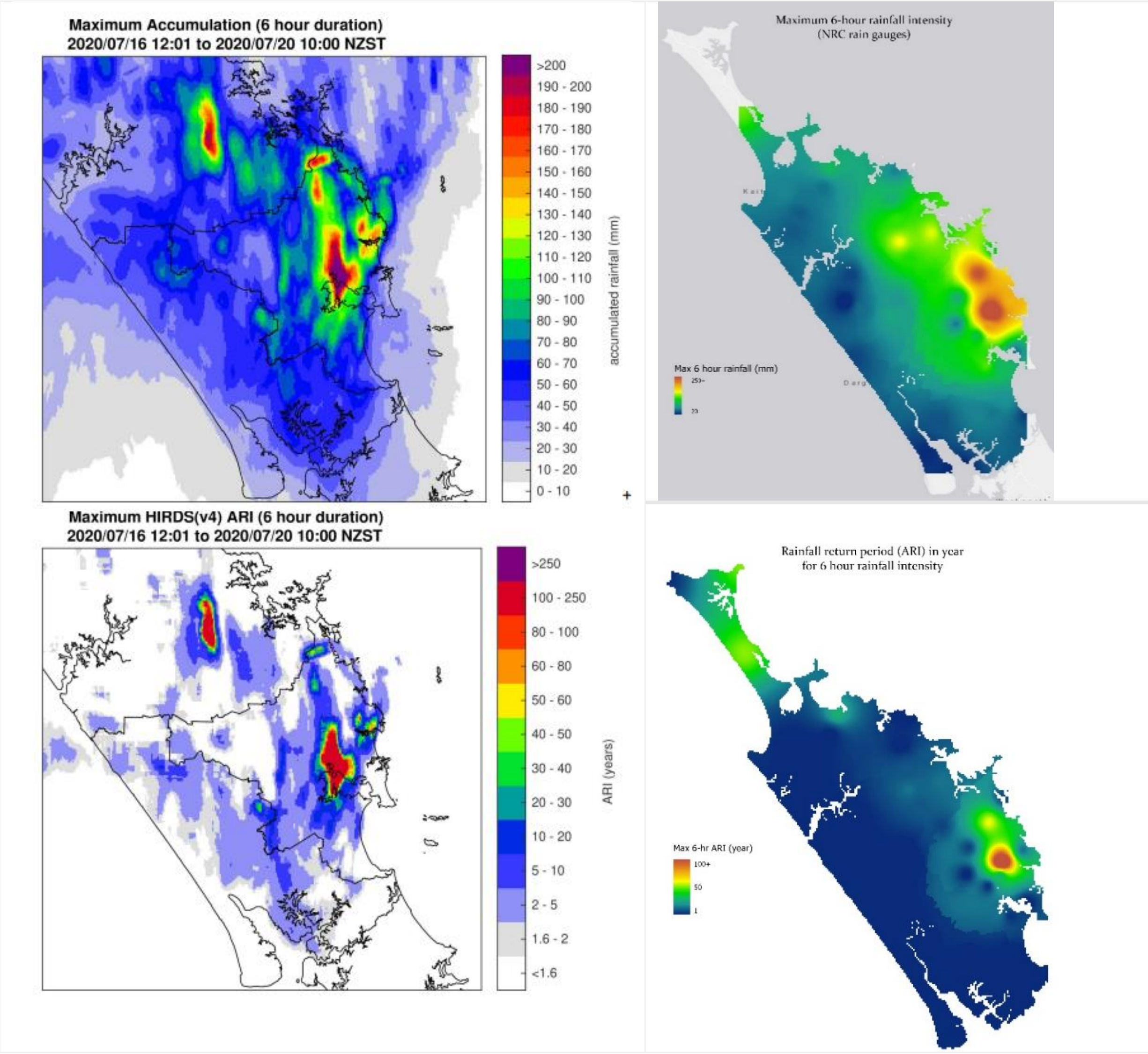




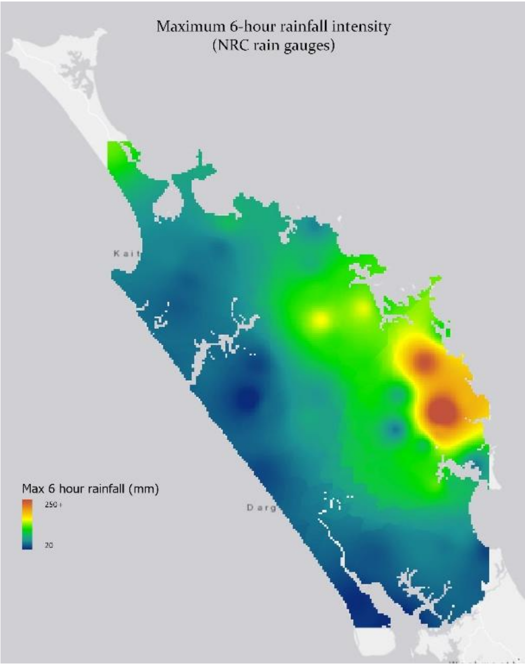


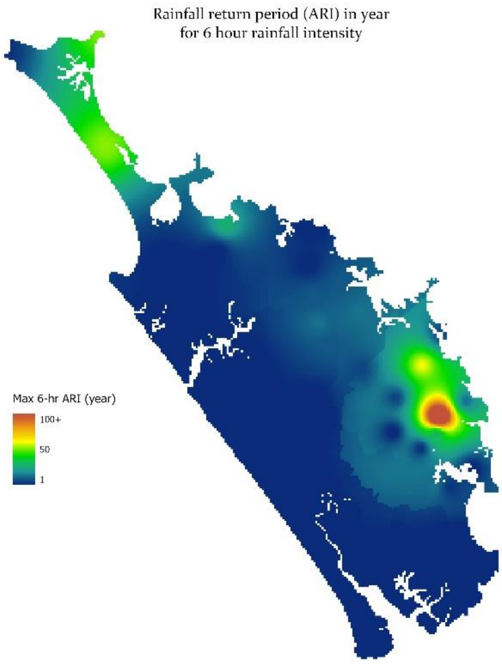


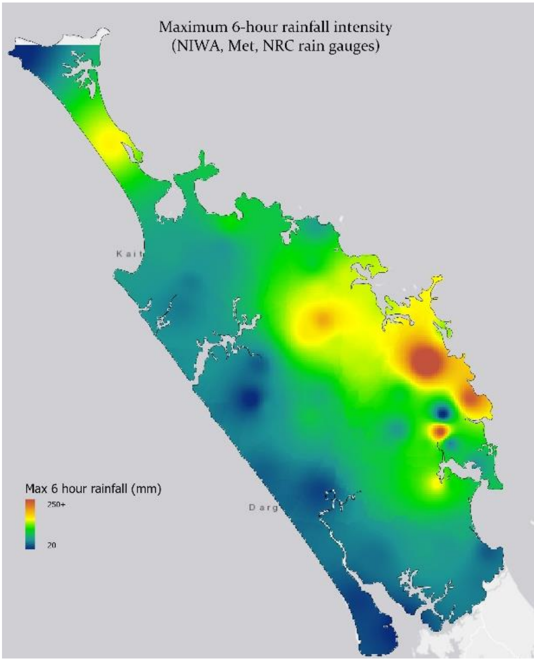
Appendix 6.2 Maximum 6-hours accumulation and return period of radar derived rainfall (left) and Northland Regional Council recorded rainfall (right).

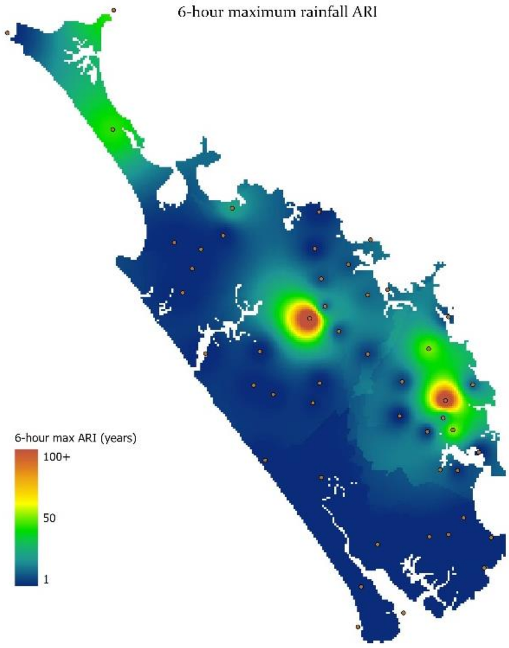


Appendix 6.3 Maximum 6-hours rainfall intensity and return periods using Northland Regional Council rain gauges (above) and using all NIWA, MET, Northland Regional Council rain gauges (below):



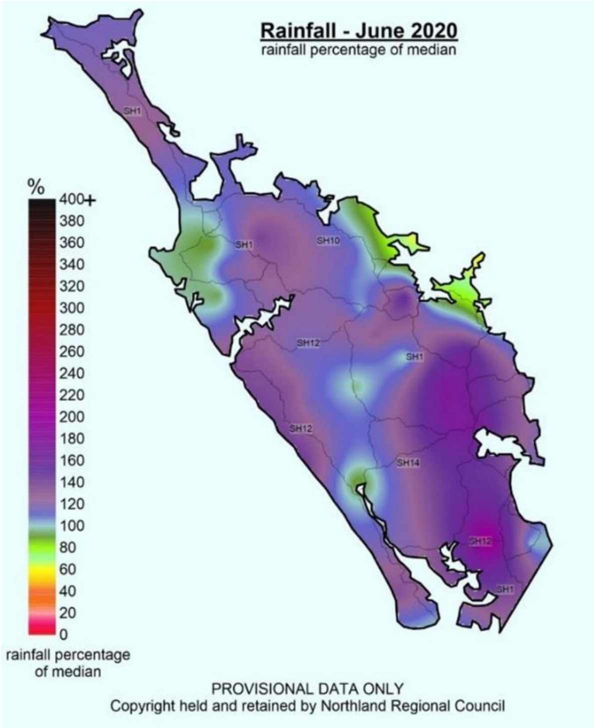


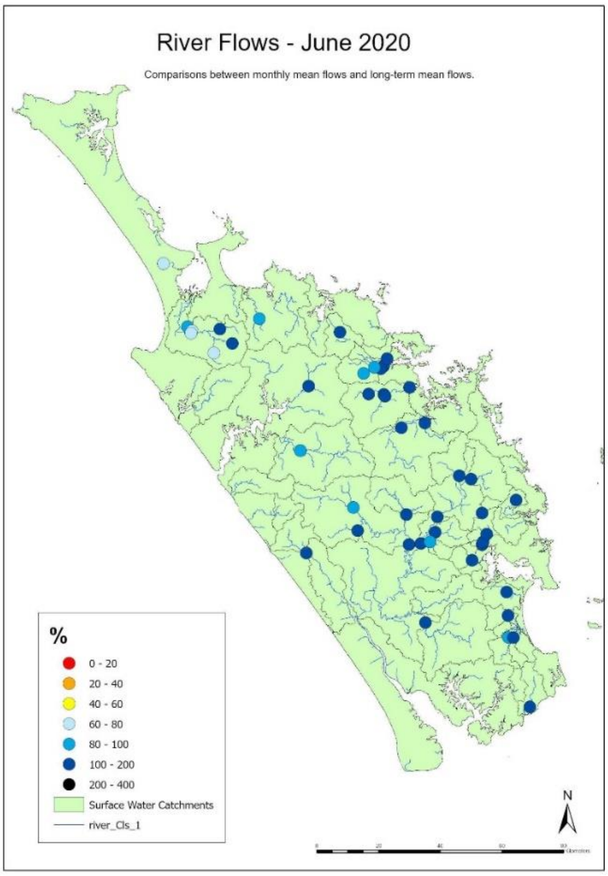




Appendix 7: Rainfall, flow, depth, and rainfall total.

Appendix 7.1 - Rainfall and flow prior to the storm/flood.





Appendix 7.2 – Rainfall depth for different durations

Site Name	30- mins	1hour	6hours	24hours	3 days
Hatea at Glenbervie Forest HQ	60	72.8	204	261	443
Waiarohia at NRC Water St	50.6	76	148	210	295.2
Whakapara at Puhipuhi	45	63	177	272	434.5
Waitangi at Ōhaeawai	39	45	118	238	345.5
Waihopo at Kimberley Road	17.5	26	101	123	166.5
Otiria at Ngapipito	27	42.5	91	189	287.5
Waikokopa RG at McDonnell Road	31	44.5	98	175	242.5
Kerikeri at BOI Golf Club	22	30.7	92	133	265.5
Ngunguru at Dugmores Rock	38	51	140	235	353
Oruru RG at Bowling Club	32	44.5	72.5	131	182
Kaeo at Bramleys	29.5	36.8	67	99	188.5
Waitangi at McDonald Road	20.5	26	115	162	277.5
Okarika at Rowland Rd	22	32.8	67	130	210.5
Oakura Bay at Te Kapua Street	36.5	62	85	187	322
Waitangi at Wiroa Road	26	36.5	93.7	132	320.5
Veronica Channel at Opua Wharf	24	36	89.5	142	238
Mangakahia at Twin Bridges	9	14.5	55.6	132	189
Opouteke at Brookvale	13	16.5	63.4	147	205
Waiharakeke RG at Okaroro Road	17.5	30.5	89.6	145	213.5
Otaika at Cemetery Road	17	23.5	74.8	135	213
Waiwarawara Rain at Wilsons Dam	14.2	22.6	71.7	131	188.5
Tarawhataroa at Larmer Road **(Kaitaia)**	18.5	24	50.4	115	144
Takahue at Te Rore	13.5	19.5	45.6	115	137
Te Puhi at Mangakawakawa Trig	21	27	45	135	192
Rotokakahi at Kohe Rd	15.5	25.5	39.2	117	136.5
Waipao at Draffins Rd	9.5	15.5	48.1	98	155.5
Waihoihoi at Brynderwyn	10	15.5	53.4	112	168
Paparoa at Maungaturoto	8.9	12.3	46.6	92	131.5
Paparoa at Taylors	8	11.7	49.7	100	139.5
Hakaru at Topuni Creek Farm	8	13.5	39.9	71	131.5
Warkworth	8	13.5	28	56	80.6
Whawharu at Topu B Taheke	6.5	8.5	33.2	86	125.5
Whangarei Harbour at Marsden Point	8.5	13.5	46	86	162
Takahue at Saddle Road	17.5	22	39.6	115	131.5
Kaiiwi at Kaiiwi Lakes	8.5	12	33.8	68	99
Dargaville at Climate (NIWA)	3.9	7.8	28	61	101.4
Awaroa at Wallace Road	5.5	10	37.3	68	86
Touwai at Weta	14.5	19.5	50	82	164
Hokianga Harbour at Omapere/Opononi	4	7	45	52	73
Waimamaku at Weka Weka Road	6	9	20.6	92	151.5
Waima at Tutamoe	13.5	17	43.9	96	171.5
Hakaru at Tara	5.7	9.1	32.9	83	134.5
Okoraka at Ngatawhiti Road	3.5	6	26.4	50	73.5

Kaipara Harbour at Pouto Point	3.5	6	18.9	32	39.5
Cape Reinga	17.5	26	17	67	100.6
Kaikohe	5.5	10.9	101	262	386.6
Whangarei Airport	5.2	10.4	41.7	250	358

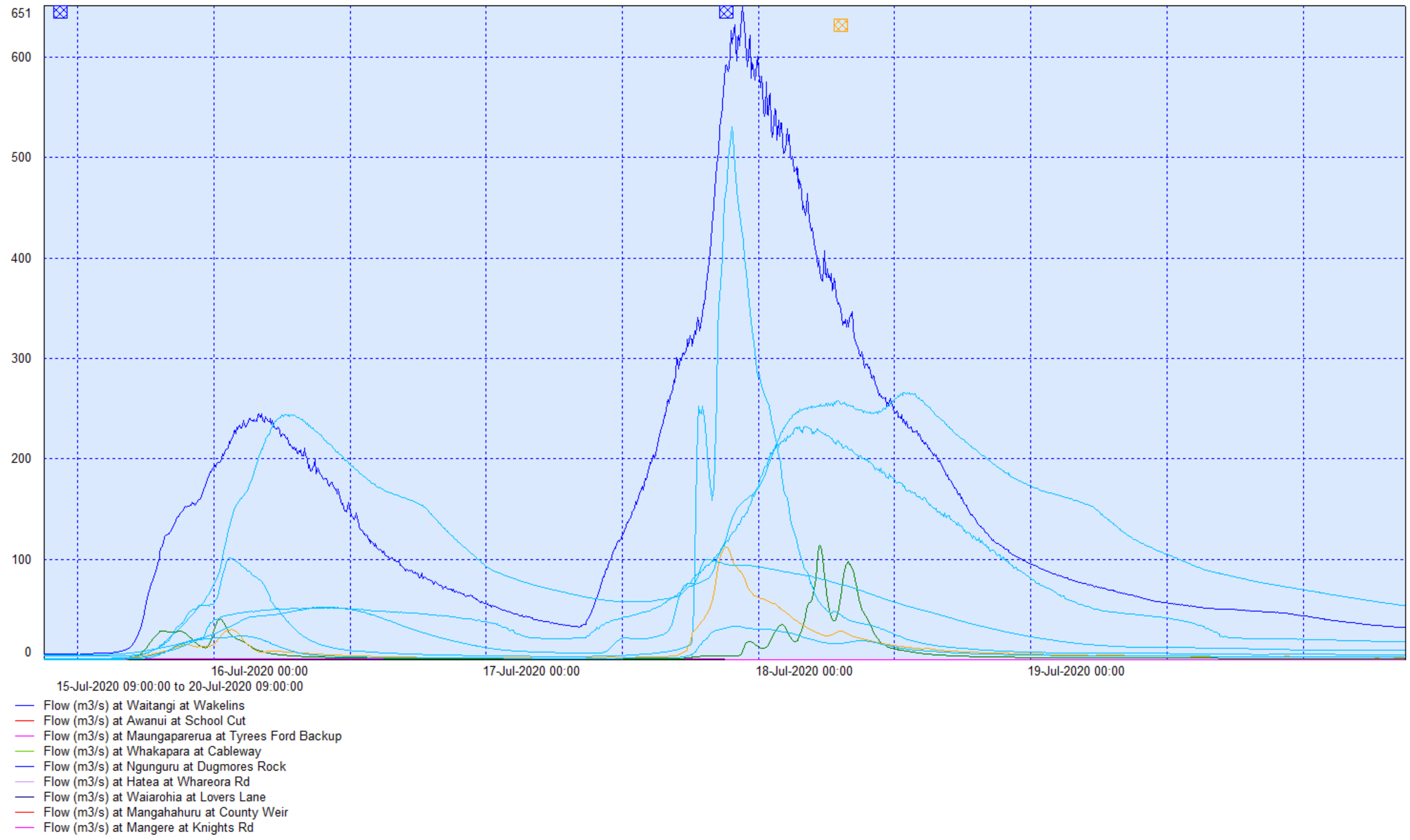
Appendix 7.3 - Rainfall total (mm) during 15-17 July 2020 with 100-year estimates at selected rain gauges

	Duration					
Gauge	**30 min**	**1 hour**	**6-hour**	**12-hour**	**1-day**	**3-day**
Tarawhataroa at Larmer Road (*)	32	61	100	118	166	201
Kaeo at Bramleys (*)	46	70	169	349	368	385
Kaikohe	5.4	10.7	64	128	257	385
Waitangi at Ōhaeawai	43	56	155	222	284	384
Hokianga harbour at Omapere/Opononi (*)	46	65	117	145	176	218
Ngunguru at Dugmores Rock	64	81	176	276	372	506
Whakapara at Puhipuhi	66	98	221	283	327	437
Hātea at Glenbervie Forest	62	84	227	279	298	410
Waiarohia at Northland Regional Council Water Street (*)	54	81	241	311	317	347
Dargaville	17	34	107	140	143	187
Warkworth	9	18	48	95	198	218

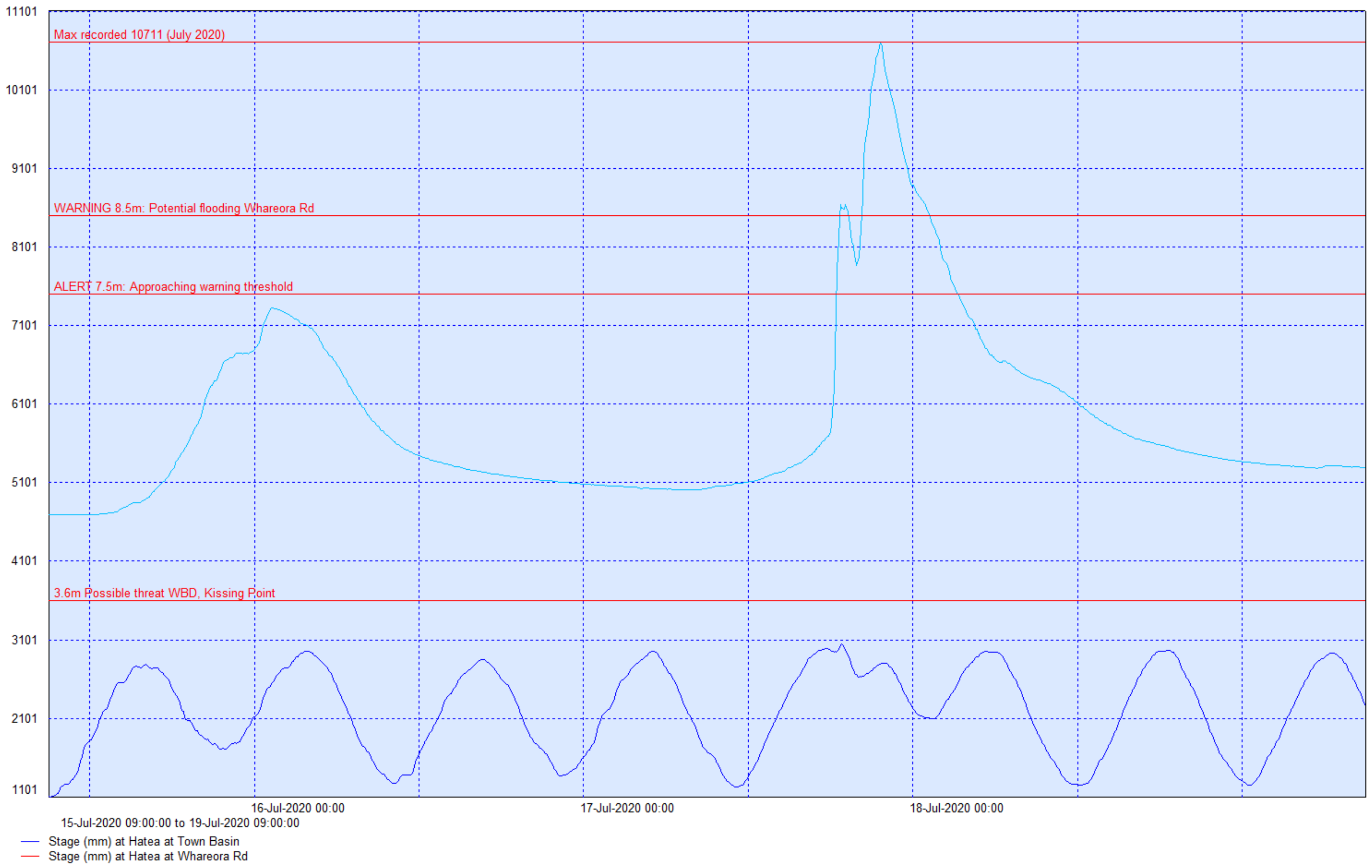
Note: (*) Estimation of high return period storm rainfall at this rain gauge is subjected to its data length.

Appendix 8: Peak flow and river water levels.

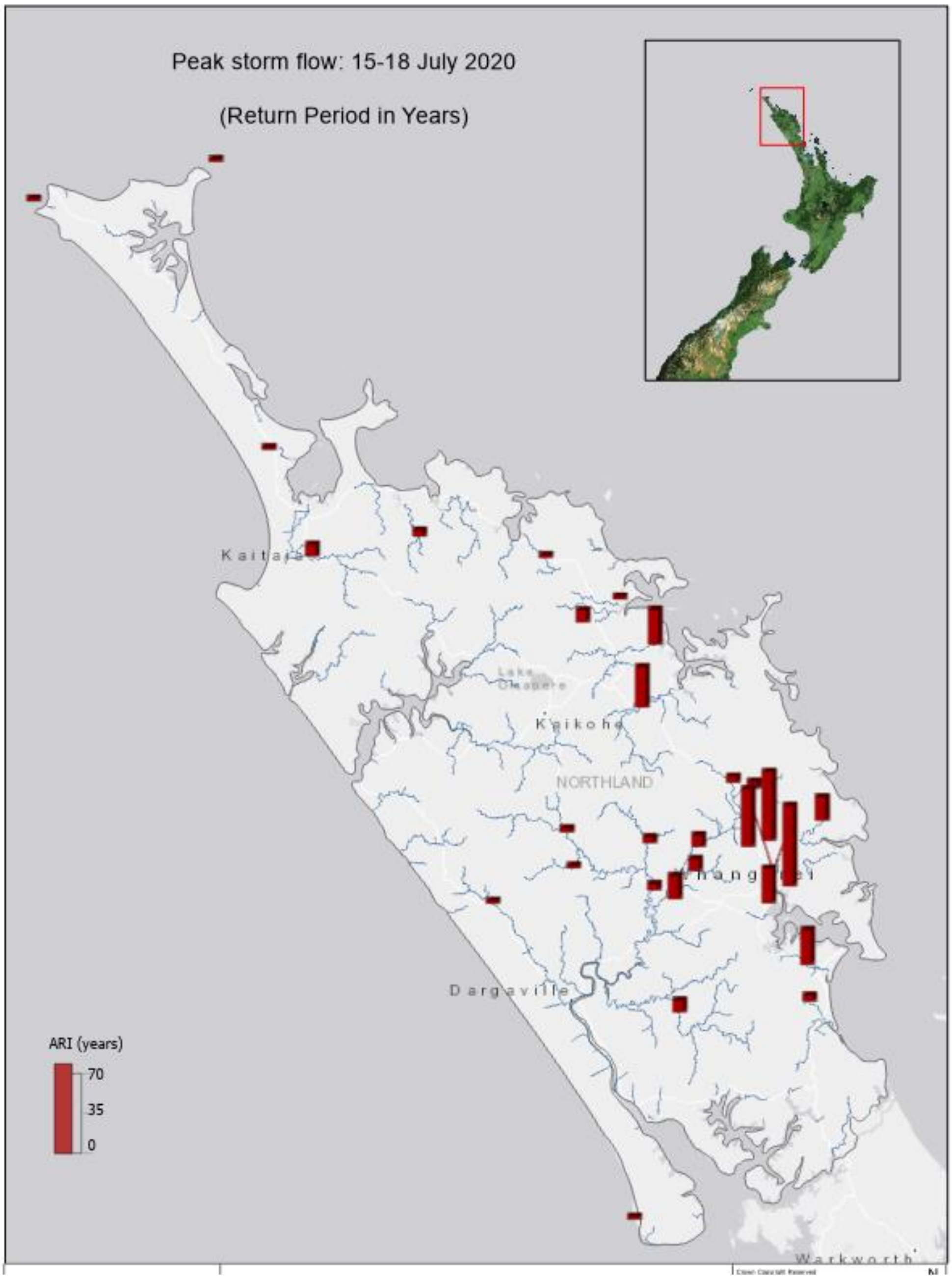
Appendix 8.1 - Peak flow during 15-19 July 2020



Appendix 8.2 River water level vs Tide level during 15 – 19 July 2020



Appendix 9: Flood flow ARI estimation.



Appendix 10: Estimated frequency of flood flows.

Flow station	Record length (N)	Area (km^2)	Peak flow (m^3/s)	Return period (years)
Awanui at School Cut	1958	222	233	11
Kaeo at Waiare Road	2008	72	114	2
Waitangi at Wakelins	1979	302	651	31
Maungaparerua at Tyrees Ford	1967	11	70	10
Whakapara at Cableway	1959	162	265	6
Ngunguru at Dugmores Rock	1969	12.5	114	14
Hātea at Whareora Road	1986	39	531	42
Waiarohia at Lovers Lane	1979	18.6	112	55
Raumanga at Bernard Street	1979	64	81	21
Ruakaka at Flyger Road	1984	45	135	32
Manganui at Permanent Station	1960	411	212	5
Wairua at Purua	1960	544	287	8
Wairua at Wairua Bridge	1961	707	438	21
Mangakahia at Gorge	1960	246	598	33
Rangitane at Stirling	2001	32	20	1
Hikurangi at Moengawahine	1960	189	236	2.6
Opouteke at Suspension Bridge	1984	105	233	2
Kaihu at Gorge	1970	116	118	2
North at Applecross	1982	38	60	7
Mangahahuru at County Weir	1968	20	33	25
Mangere at Knights Road	1983-	79	99	12
Waiotu at SH1	1987	125	160	6
Waihoihoi at St Mary Rd	1984	25.1	24	3
Waipao at Draffins Rd	1979	36.7	27	29
Waiharakere at Willowbank	1967	229	215	28
Waiaruhe at Paketona	1967	2.2	7	1

Appendix 11: Comparison of July 2020 and Jan 2011 surveyed flood levels at selected locations around Whangārei CBD.

Catchment	2011 flood level (NZVD)		2020 flood level (NZVD)		Note
	ID	Level	ID	Level	
Waiarohia Raumanga	*100*	52.7404	*4780*	58.0243	Before dam
Waiarohia Raumanga	*99*	28.2017	*4682*	28.1957	Another side of Maunu Road
Waiarohia Raumanga	*105*	16.7512	*4599*	17.6203	35m apart
Waiarohia Raumanga	*4611*	6.9904	*4611*	6.0514	WL at sensor 2
Waiarohia Raumanga	*60*	4.3206	*4657*	4.2159	
Waiarohia Raumanga	*37*	10.6826	*36*	11.0726	
Waiarohia Raumanga	*95*	2.3388	*4577*	2.4389	
Hātea	*6*	72.8534	*4600*	73.1364	
Hātea	*17*	22.6231	*4698*	22.9486	
Otaika	*274*	4.4497	*312*	4.2857	3.9356 (2007 survey) #299

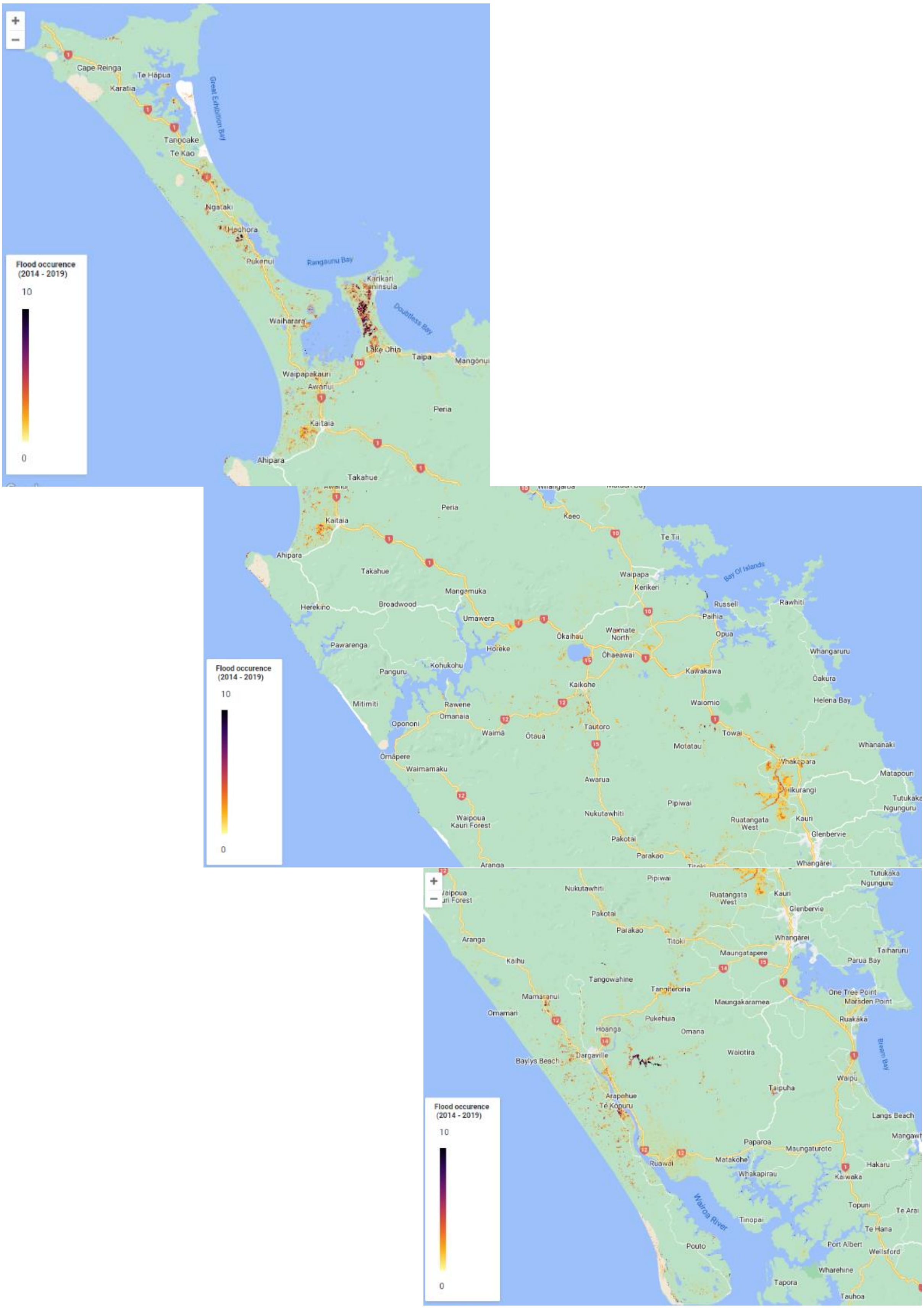
Note: flood levels were surveyed to NZVDatum.

Appendix 12: Flood occurrence in Northland.

Appendix 12.1 – Sentinel-1 radar backscatter: Darker areas highly likely represent surface water. The image from 5 July (above) is before a flood; the image from 17 July (below) is during a flood event.

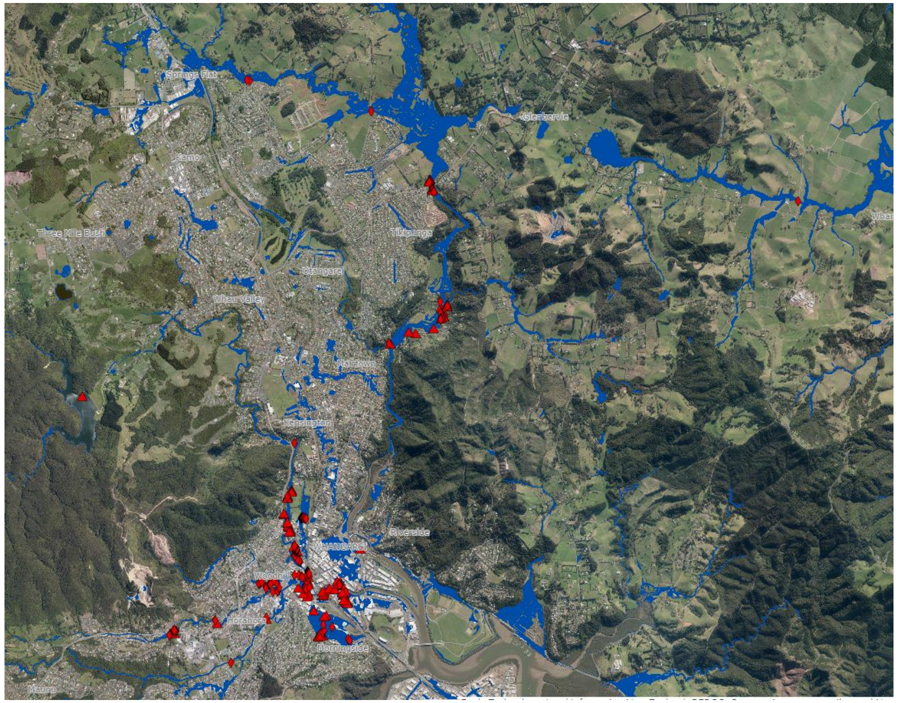
(Source: floods · Wiki · EnviroSatTools / Documentation · GitLab).

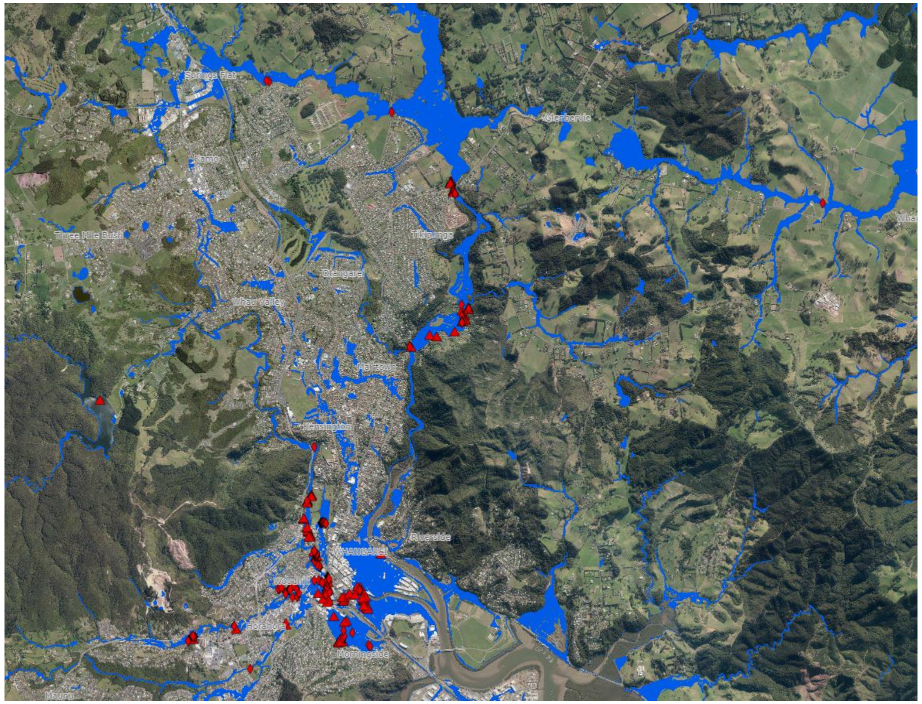
Appendix 12.2 - Snapshot of flood occurrence in Northland during 2014 – 2019 period



(Source: Wiki · EnviroSatTools / Documentation · GitLab)

Appendix 13: Snapshot of Whangārei flood extent with 10-year return period (left) and 50-year return period (right) regionwide model in blue colour.





Note, flood gauges are marked in red colour.

Appendix 14: Hopua te Nihotetea retention dam in normal condition and during the July 2020 event.

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Northland
REGIONAL COUNCIL
Te Kaunihera ā rohe o Te Taitokerau