Waikato Regional Council Technical Report 2017/20

Regional flood summary:
Ex-Tropical Cyclone Debbie (4-6 April), Tasman Low (11-13 April), and Ex-Tropical Cyclone Cook (13-14 April)

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Executive Summary

Two ex-tropical cyclones and a low pressure system, (Ex-Tropical Cyclone Debbie, Tasman low, and Ex-Tropical Cyclone Cook) made landfall in New Zealand on 4 April, 11 April, and 13 April respectively. These events followed an earlier period of intense rainfall in parts of the Waikato region during March 2017 (refer to seprate Report Doc# 10588909). Reporting of these events in summarised in Table 1.

Table 1: Summary of weather event reporting of March and April 2017 weather events.

Event	Date	Reference
Tasman Tempest	7 – 12 March 2017	Doc# 10588909
Ex-Tropical Cyclone Debbie	4 April 2017	Doc# 10589816
Tasman low	11 April 2017	Doc# 10589816
Ex-Tropical Cyclone Cook	13 April 2017	Doc# 10589816

The purpose of the report is to:

- summarise the rainfall events, and the observed river flows and water levels that resulted;
- describe the response of the Waikato Regional Council (WRC) to these events;
- provide the rainfall and flood frequency relationships to inform additional scheme-specific performance reporting;
- and capture the chronology of events detailed in the Situation Reports issued by WRC offices during the events.

The report is not intended to describe or quantify the performance of WRC-managed flood protection schemes and/or land drainage schemes. This will be completed in subsequent level of service reviews and assessments.

The effects of the events were felt across the Waikato Region with the Waihou River, Piako River and lower Waikato River systems being the worst affected. Rainfall totals were the highest in the Coromandel Peninsula with Ex-Tropical Cyclone Debbie bringing higher rainfall totals than Ex-Tropical Cyclone Cook.

Correlating the magnitude of the events and flows to the collective impacts on highly saturated catchments is challenging, as it is difficult to capture cumulative effects in single measurements. Despite this, the magnitude of the events have been considered across a number of telemetered sites for a range of durations in order to gain an understanding of overall maximum magnitude.

The rainfall site at Otaipuhi (northwestern side of Lake Taupō) had an annual exceedance probability (AEP) of 1-2 % for 48 hour rainfall for Ex-Tropical Cyclone Debbie, the Maukoro Landing (northern end of Kopuatai peat dome) rainfall site had an AEP of 2-5 % for 48 hour rainfall for Ex-Tropical Cyclone Debbie. Ex-Tropical Cyclone Cook did not produce AEP's for rainfall sites (48 hour rainfall) of the same magnitude as Ex-Tropical Cyclone Debbie with the maximum AEP of 10-20 % being recorded at the rainfall site Kaimai Summit. The maximum AEP for total volume of water over a 14 day period during April 2017 was recorded at Piako River at Paeroa Tahuna Road with an AEP of < 1 % and the Waitoa River at Mellon Road with an AEP of < 1 %.

Stopbank overtopping occurred on the Kerepehi No 2 (Awaiti South), Carters Cutoff (Awaiti South), and Pitts Road (Torehape) stopbanks (Piako scheme) due to floodwaters generated from Ex-Tropical Cyclone Cook.

The three April weather events caused disruption and damage to property and infrastructure across the Waikato Region with the Hauraki Plains and Lower Waikato the worst affected with several dwellings flooded as well as widespread road closures.

Emergency ponding areas in the Piako scheme operated as the events were over the 5-10% AEP design standards for spilling into these ponding zones. In general, the flood protection schemes performed to the levels expected. Some issues did arise as a result of the cumulative effects of the successive events with larger than design flows (i.e., Piako scheme) and the impacts of prolonged high water levels (i.e., Sampsons stopbank). Detailed analysis of flood protection scheme performance will be undertaken as part of upcoming level of service reviews.

1 Overview of Events

1.1 Ex-Tropical Cyclone Debbie (4-6 March)

Cyclone Debbie reached its peak over the Whitsunday Islands on 28 March 2017 as a Category 4 system, with wind gusts of up to 250 km/hour. As the cyclone remnants weakened and travelled south-east, a low pressure system formed along the frontal boundary of the system. This low pressure system (Ex-Tropical Cyclone Debbie) pushed tropical moisture south from the Pacific Islandscausing the heavy rains and high humidity levels produced by the system.

Ex-Tropical Cyclone Debbie made landfall in New Zealand on the 4 April (Figure 1). The non-frontal, low pressure system caused heavy rainfall across the Waikato Region, however was relatively short-lived with heavy rainfall easing by the early hours of the 6 April (48 hours; Table 2).

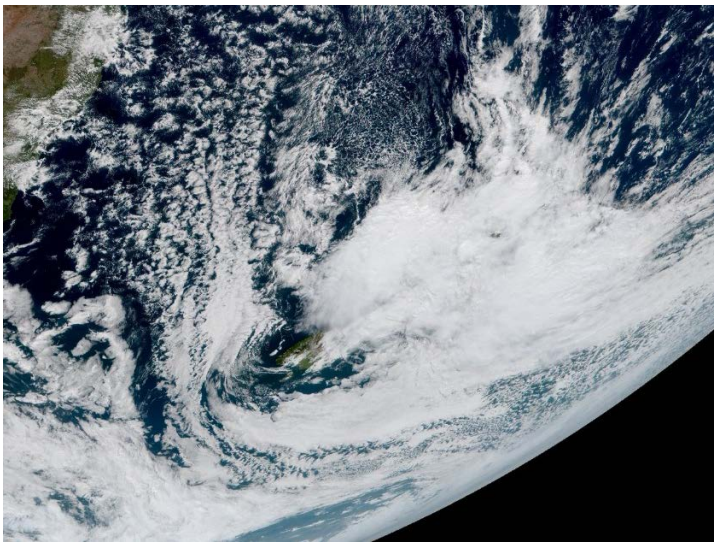

Figure 1: Satellite image showing Ex-Tropical Cyclone Debbie and associated low pressure systems over New Zealand on 4 April (Photo credit: NIWA Weather Twitter).

Table 2: 12 hour rain totals throughout the Ex-Tropical Cyclone Debbie event.

	Monday 3	Tuesday 4		Wednesday 5		Thurs 6	3 day total
	12:00-00:00	00:00-12:00	12:00-00:00	00:00-12:00	12:00-00:00	00:00-12:00	
Castle Rock	0.0	14.0	126.0	57.7	36.5	0.5	234.7
Pinnacles	0.0	19.0	102.0	77.0	43.5	0.5	242
Golden Cross	0.0	23.0	44.0	19.0	24.5	0.0	110.5
Te Aroha	0.0	19.5	49.0	26.0	21.0	0.0	115.5
Kaimai	0.0	24.5	58.0	30.0	50.0	0.5	163
Maukoro Landing	0.0	23.0	57.0	31.0	31.0	0.0	142
Control Structure	5.5	7.5	85.5	29.5	10.0	0.0	138
Wairamarama	0.0	8.5	64.0	61.5	11.5	0.0	145.5
Ruakura	0.6	27.8	42.8	27.4	9.8	0.2	108.6
Puniu	0.5	38.5	49.0	37.5	9.5	0.5	135.5
Ngaroma	2.0	21.0	37.5	43.0	26.0	2.5	132
Waitanguru	2.0	72.0	49.0	66.0	13.5	7.5	210
Reid's Farm	2.0	16.0	27.5	49.5	21.0	0.5	116.5
Otaipuhi Station	15.0	43.5	58.5	61.5	22.5	0.5	201.5
Mangatoetoe	19.0	32.0	38.5	48.0	42.0	0.5	180

The maximum rainfall for the Lower Waikato was less than a 10% AEP (Annual Exceedance Probability) event over the peak 48 hours of Ex-Tropical Cyclone Debbie (Figure 2). Maximum 48 hour rainfall for the Waihou/Piako was recorded at Maukoro Landing (5 to 2% AEP; Figure 3). Rainfall at Otaipuhi Station reached a 2% AEP level when considered over 24 and 48 hours periods. This was the largest size of event recorded across the region (Figure 4; Appendix 1).

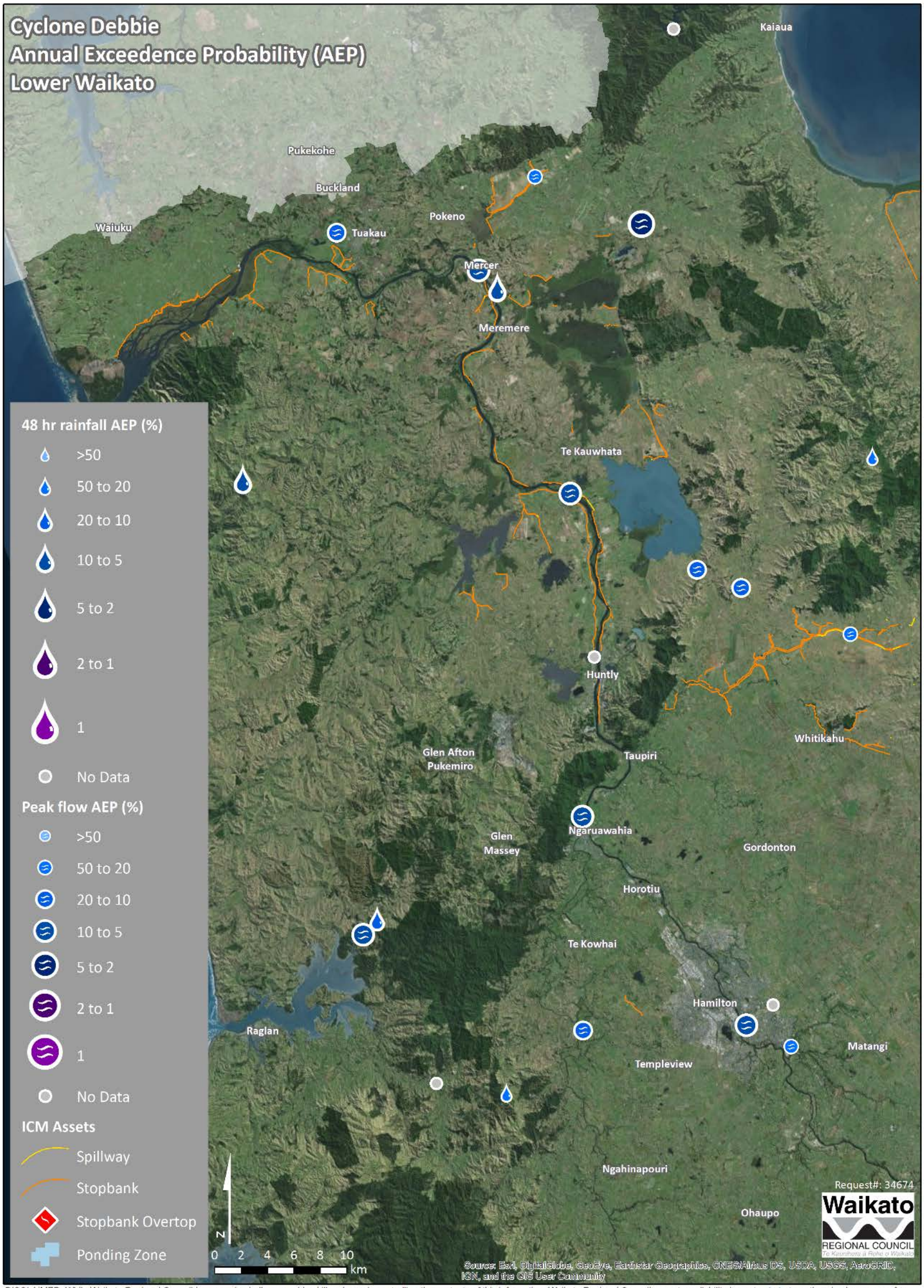

Figure 2: 48 hour rainfall and peak river flow annual exceedance probabilities (AEP) during Ex-Tropical Cyclone Debbie in the Lower Waikato.

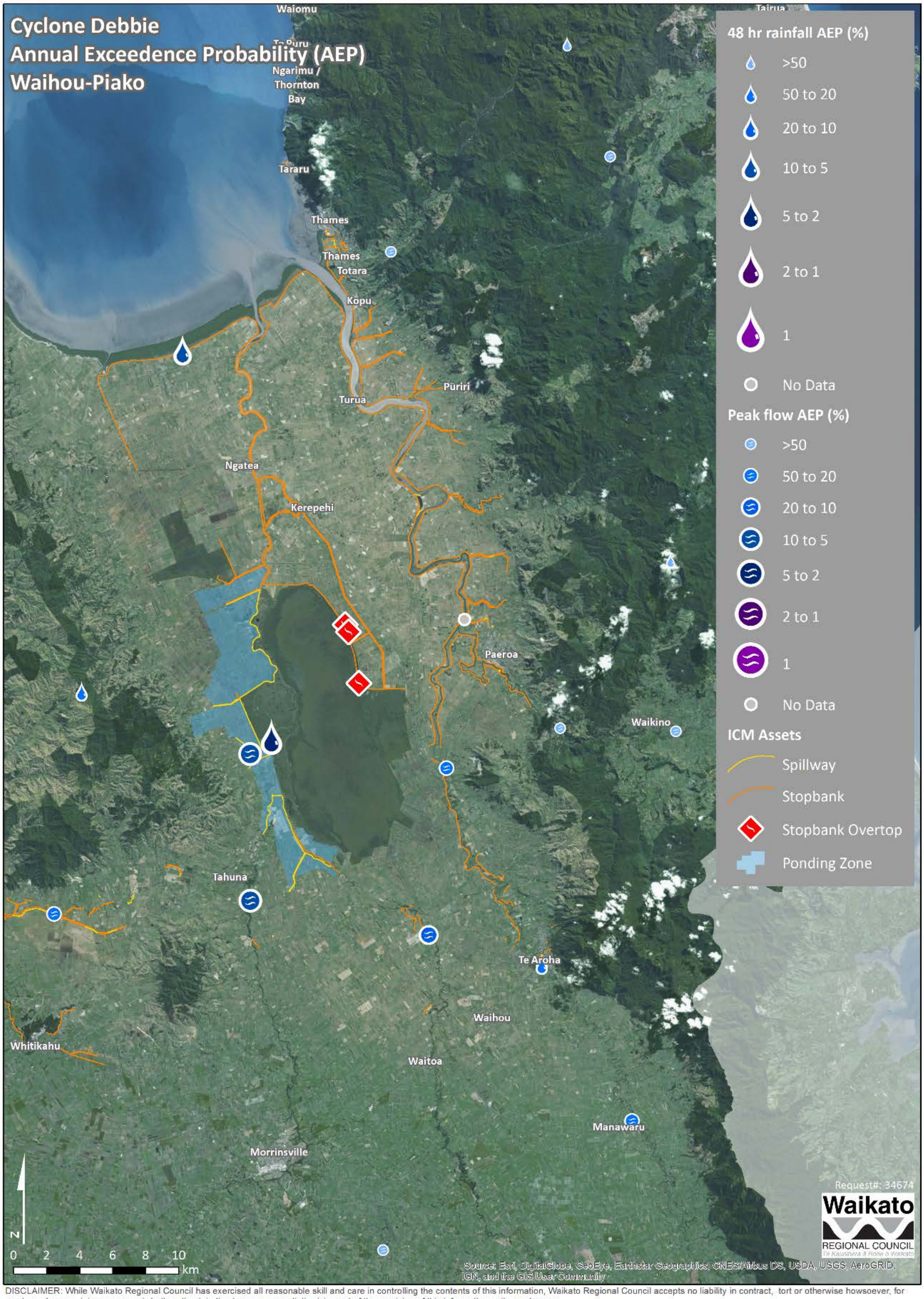

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Figure 3: 48 hour rainfall and peak river flow annual exceedance probabilities (AEP) during Ex-Tropical Cyclone Debbie in the Waihou/Piako.

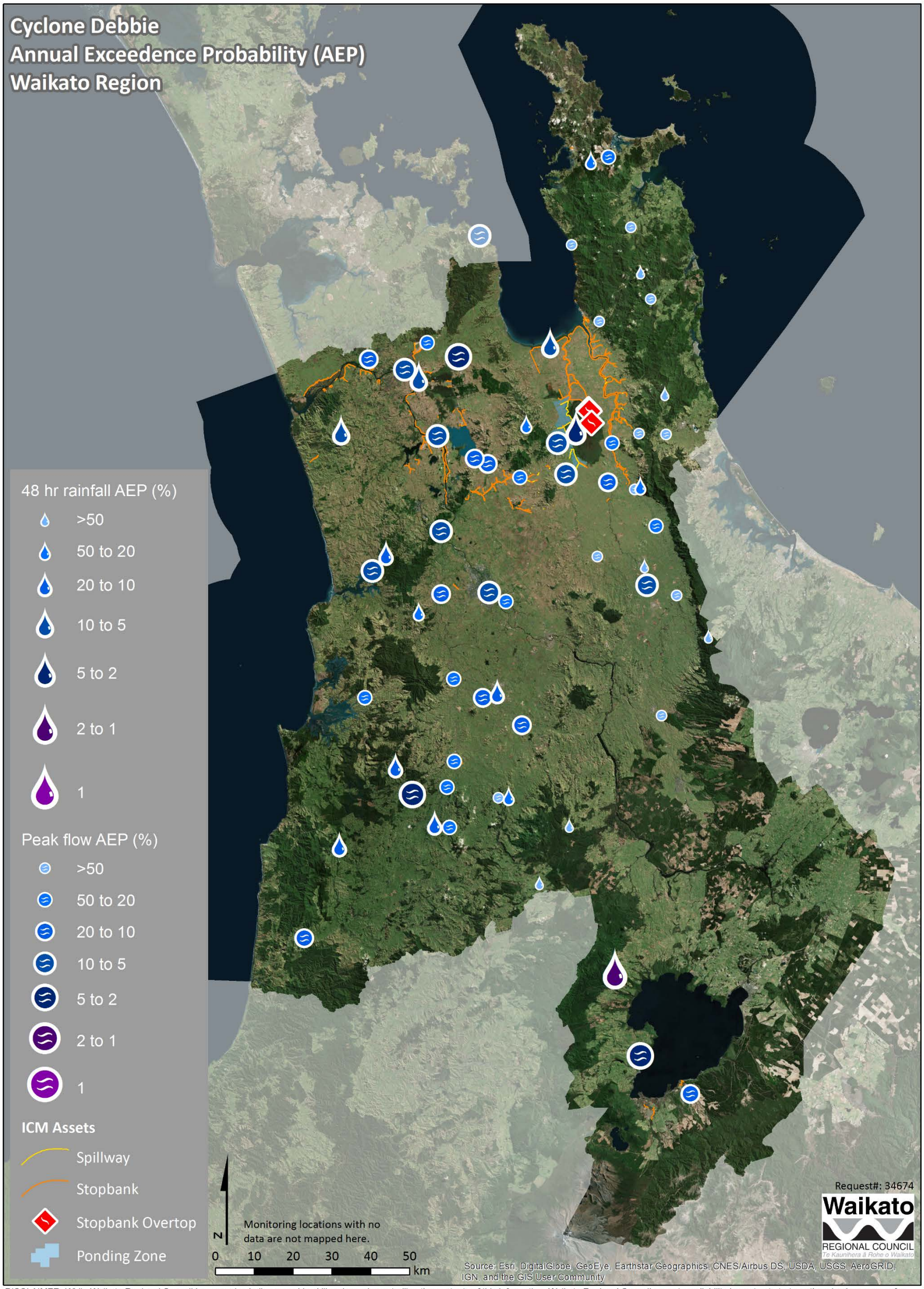


Figure 4: 48 hour rainfall and peak river flow annual exceedance probabilities (AEP) during Ex-Tropical Cyclone Debbie in the Waikato Region.

1.2 Tasman Low (11-13 April) & Ex-Tropical Cyclone Cook (13-14 April)

Less than a week after Ex-Tropical Cyclone Debbie caused heavy rainfall across much of the North Island, a second cyclonic system was identified as tracking towards the area. Cyclone Cook registered as a Category 3 cyclone as it crossed New Caledonia before weakening to a tropical storm as it neared New Zealand. NIWA scientists predicted the possibility of another cyclone affecting the region due to an active Madden-Julian Oscillation (MJO) in the equatorial region.

The MJO pulse is a large scale system of atmospheric circulation coupled with tropical convection. These lead to the formation of tropical cyclones. Systems can last for weeks or months and have the greatest impact on weather patterns during intra-seasonal times such as April (Ben Noll, NIWA). The occurrence of this type of system partially explains the quick succession of cyclone systems at this time of year.

Further complicating the situation was a low pressure system coming across the Tasman Sea that was forecast to bring heavy rain immediately before Ex-Tropical Cyclone Cook was forecast to arrive (Figure 5). This led to a period of 3 and a half days of heavy rainfall with no substantial respite for catchments to recover (Table 3).

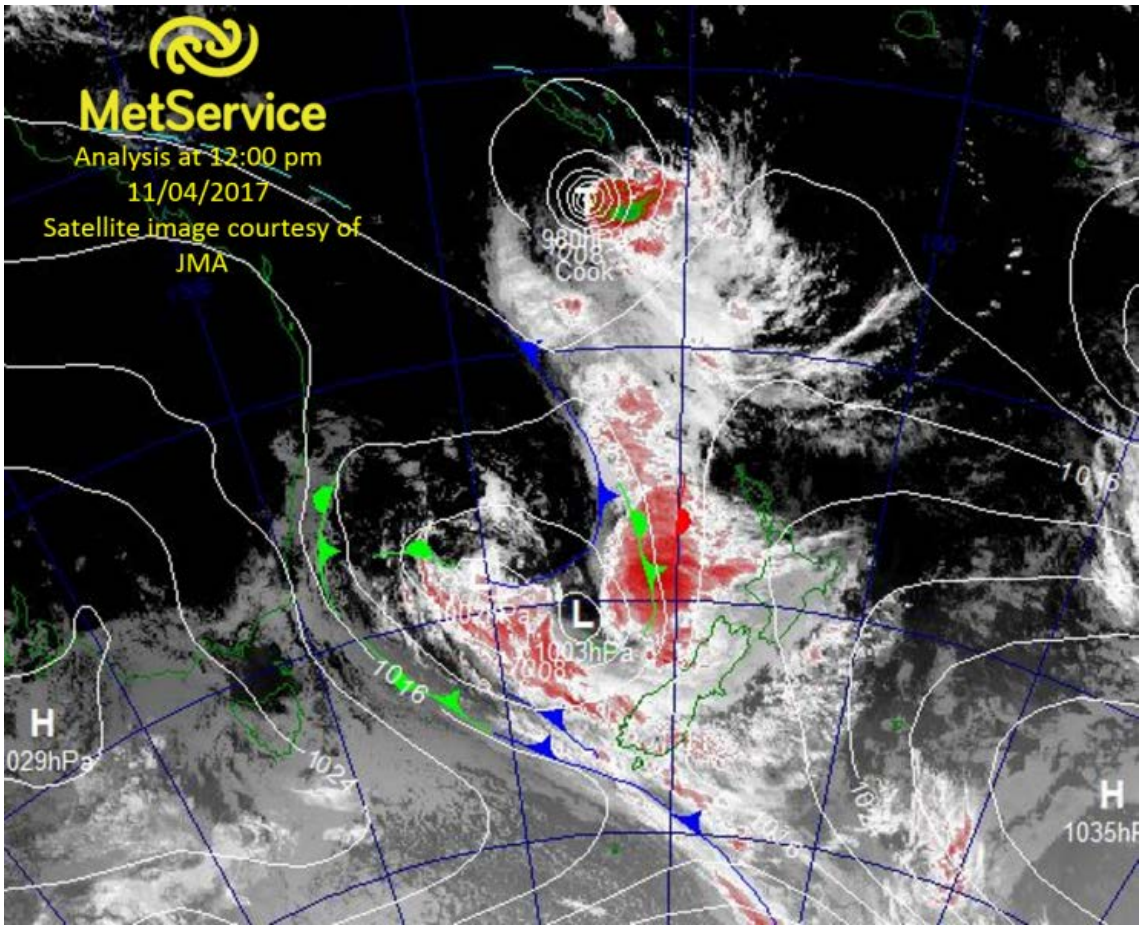
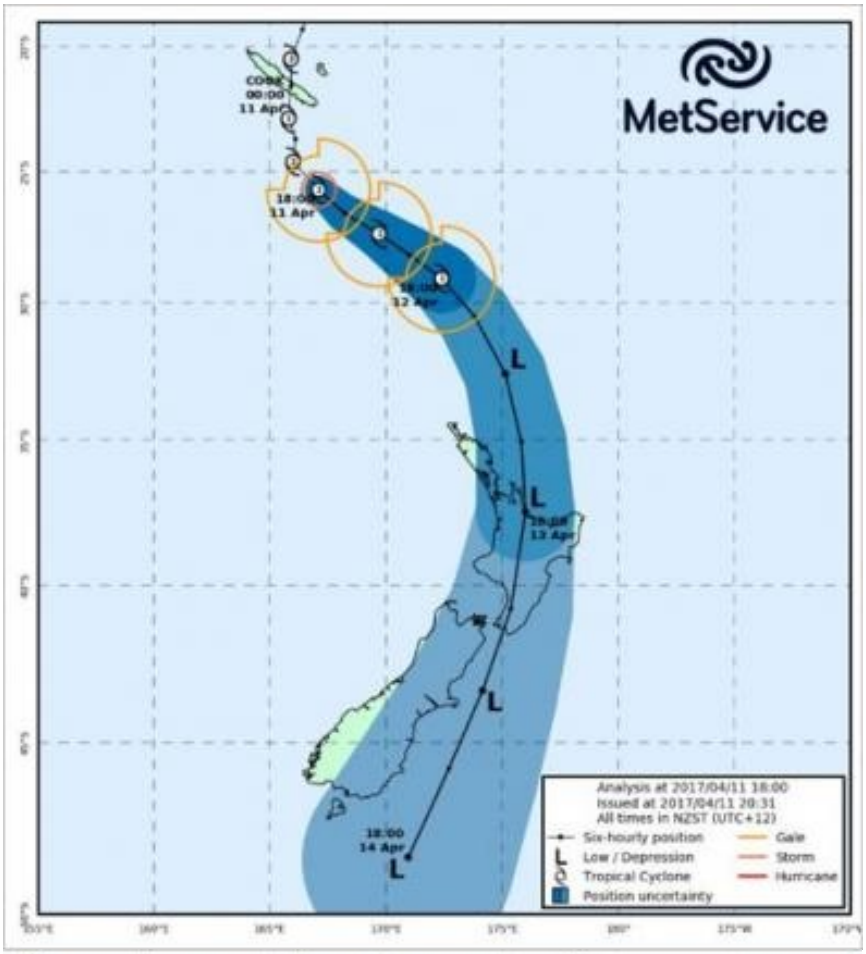


Figure 5: Satellite imagery showing the low pressure system coming from the Tasman to the west of the country and Cyclone Cook approaching from the north (11/04/2017).

Despite this, the overall impacts from Ex-Tropical Cyclone Cook were less severe than anticipated for the Waikato Region. The forecast path of the event was to track along the east coast of the Coromandel Peninsula and through Lake Taupō (Figure 6 A), however the event was faster moving and further to the east than predicted (Figure 6 B).

A)



B)

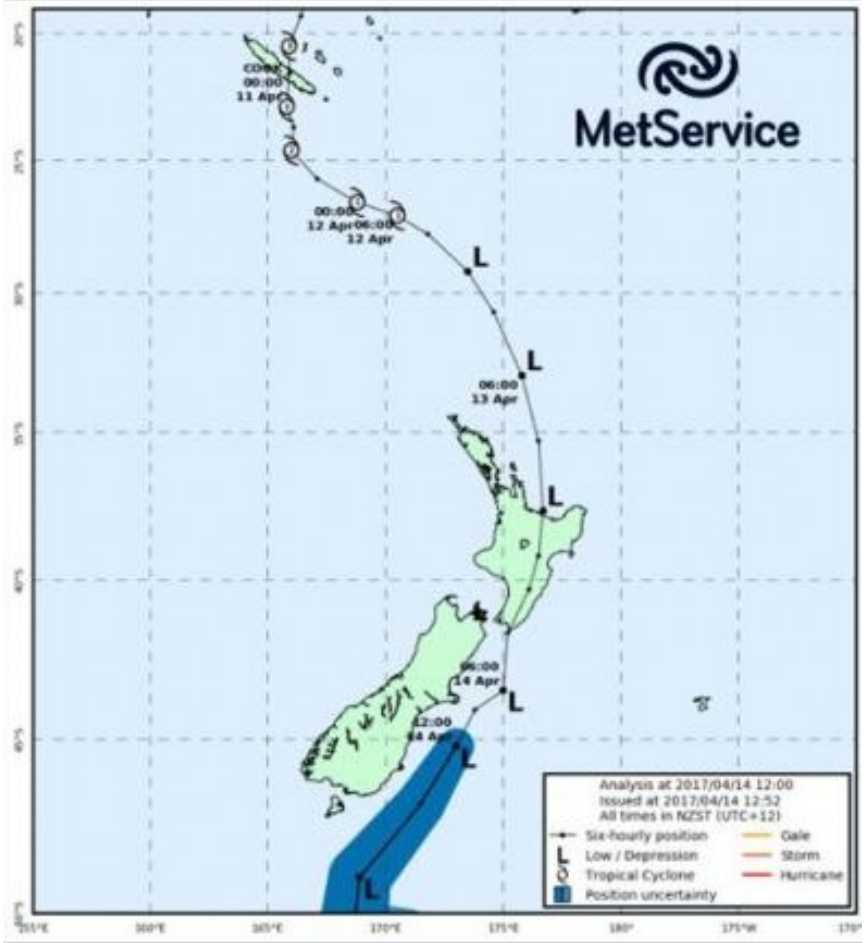


Figure 6: A) Predicted track of Ex-Tropical Cyclone Cook (11/4/2017) on which the majority of warnings were formulated on; and B) Actual track of event.

Table 3: 12 hour rain totals throughout the Tasman Low and Ex-Tropical Cyclone Cook event.

	Tues 11	Wed 12		Thurs 13		Fri 14		3.5 Day Total
	12:00-00:00	00:00-12:00	12:00-00:00	00:00-12:00	12:00-00:00	00:00-12:00	12:00-00:00	
Castle Rock	1.5	29.0	88.5	16.0	29.5	1.5	4.5	170.5
Pinnacles	3.5	34.5	81.0	27.0	48.0	1.5	0.0	195.5
Golden Cross	4.0	27.0	93.5	25.5	81.5	1.0	0.0	232.5
Te Aroha	0.0	5.0	65.5	3.0	62.5	0.5	0.0	136.5
Kaimai	2.5	30.0	123.5	15.0	79.0	2.0	5.5	257.5
Maukoro Landing	0.0	4.5	50.5	5.0	26.0	0.5	0.0	86.5
Control Structure	0.0	1.5	46.5	1.0	21.5	0.5	5.5	76.5
Wairamarama	0.0	7.5	22.0	2.5	14.5	1.0	4.5	52
Ruakura	0.0	6.0	59.8	2.4	23.4	1.0	1.0	93.6
Puniu	0.0	0.5	61.0	2.0	28.0	6.5	0.0	98
Ngaroma	0.0	0.0	66.5	10.0	42.0	18.5	5.0	142
Waitanguru	0.0	4.5	5.5	0.0	25.5	9.0	25.5	70
Reid's Farm	1.5	0.0	29.5	6.0	21.5	7.0	1.0	66.5
Otaipuhi Station	0.5	0.5	61.0	6.0	45.5	3.0	1.5	118
Mangatoetoe	3.0	2.5	66.5	10.5	14.5	4.0	1.0	102

Peak rainfall during the event occurred at Puniu, Kaimai Summit, and Te Aroha and reached between 20 and 10% AEP levels (5 to 10 year events) over 2 hour; 12, 48, 72 hours; and 20 minute periods respectively (Figure 8, Figure 9, Figure 10; Appendix 1). These rainfall levels were lower than those observed during Ex-Tropical Cyclone Debbie, however totals across the week were still significant for much of the region (Figure 7).

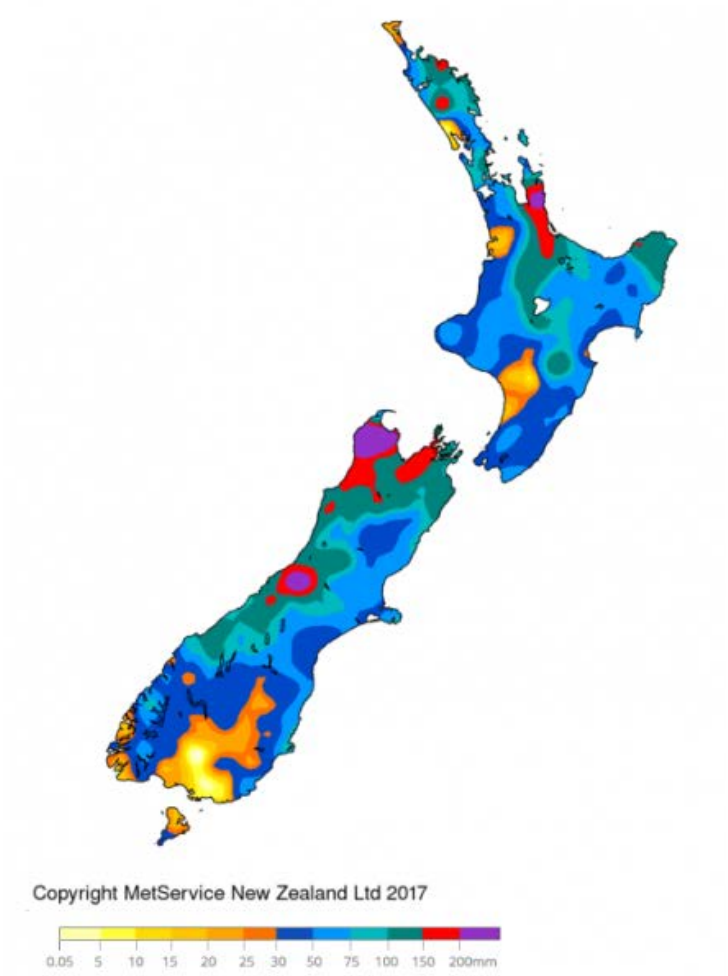


Figure 7: 7 day rainfall accumulation from 8 to 14 April (Credit: Met Service)

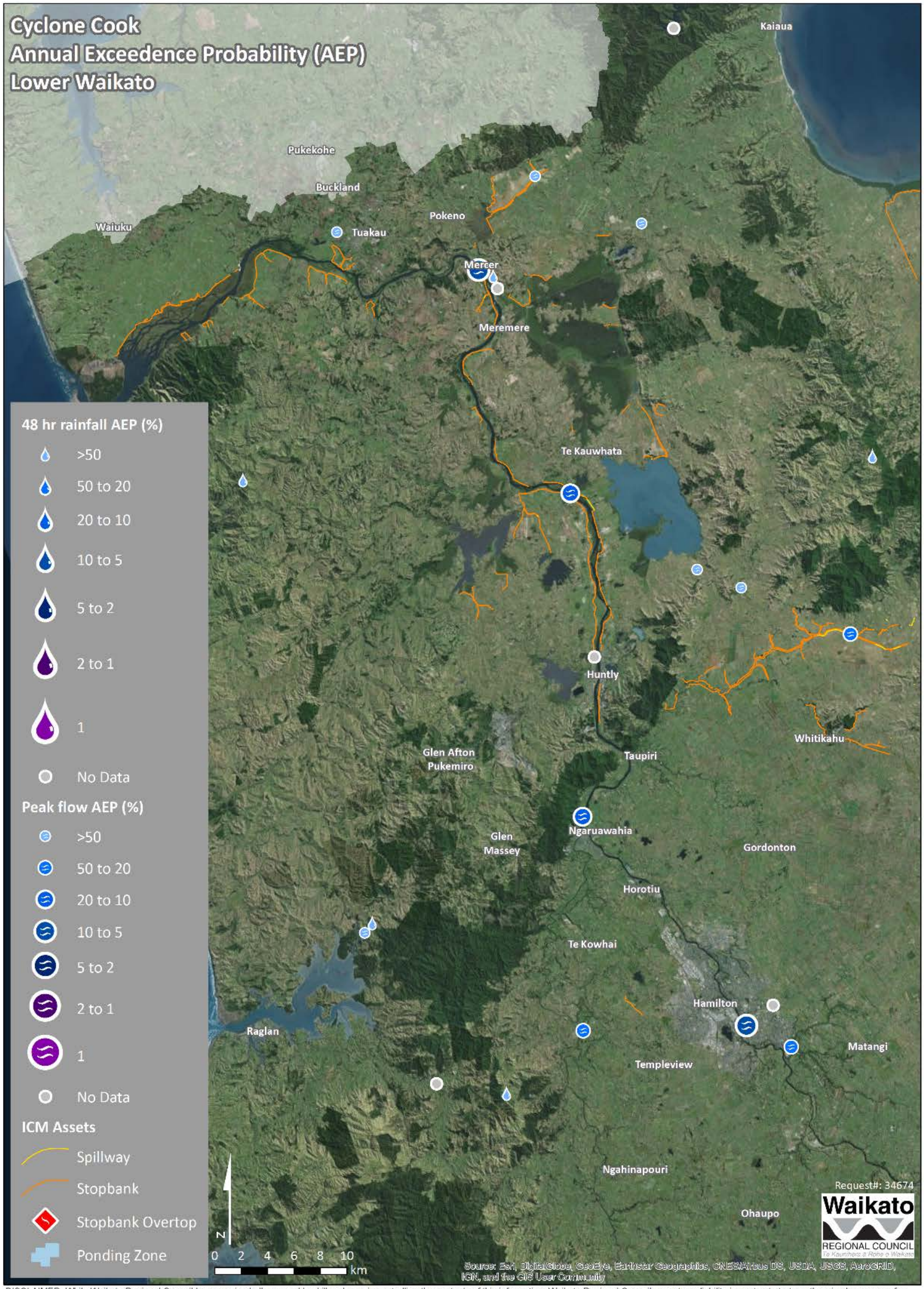


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Figure 8: 48 hour rainfall and peak river flow annual exceedance probabilities (AEP) during Ex-Tropical Cyclone Cook in the Lower Waikato.

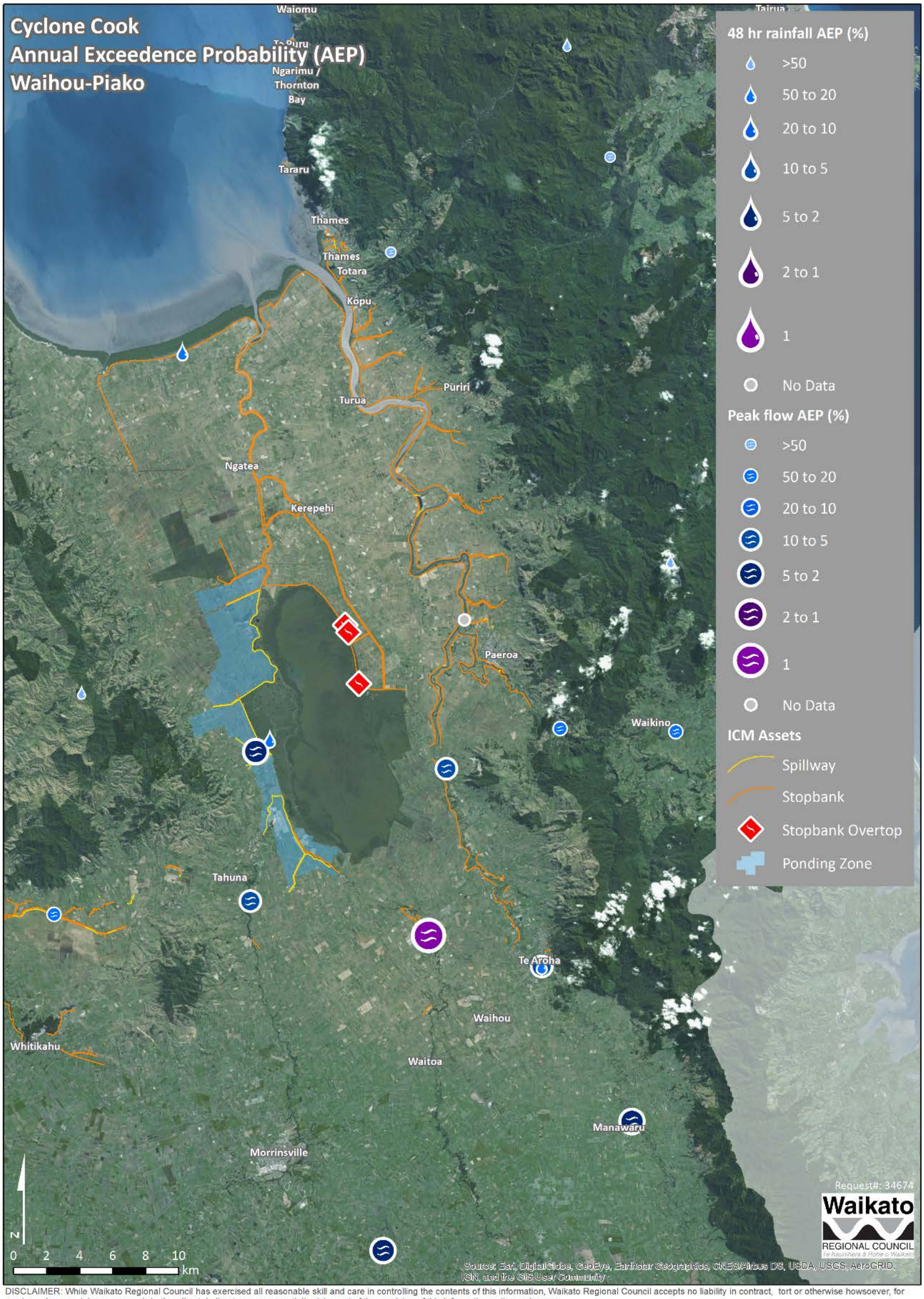

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Figure 9: 48 hour rainfall and peak river flow annual exceedance probabilities (AEP) during Ex-Tropical Cyclone Cook in the Waihou/Piako (see Table 21 for stopbank failure locations).

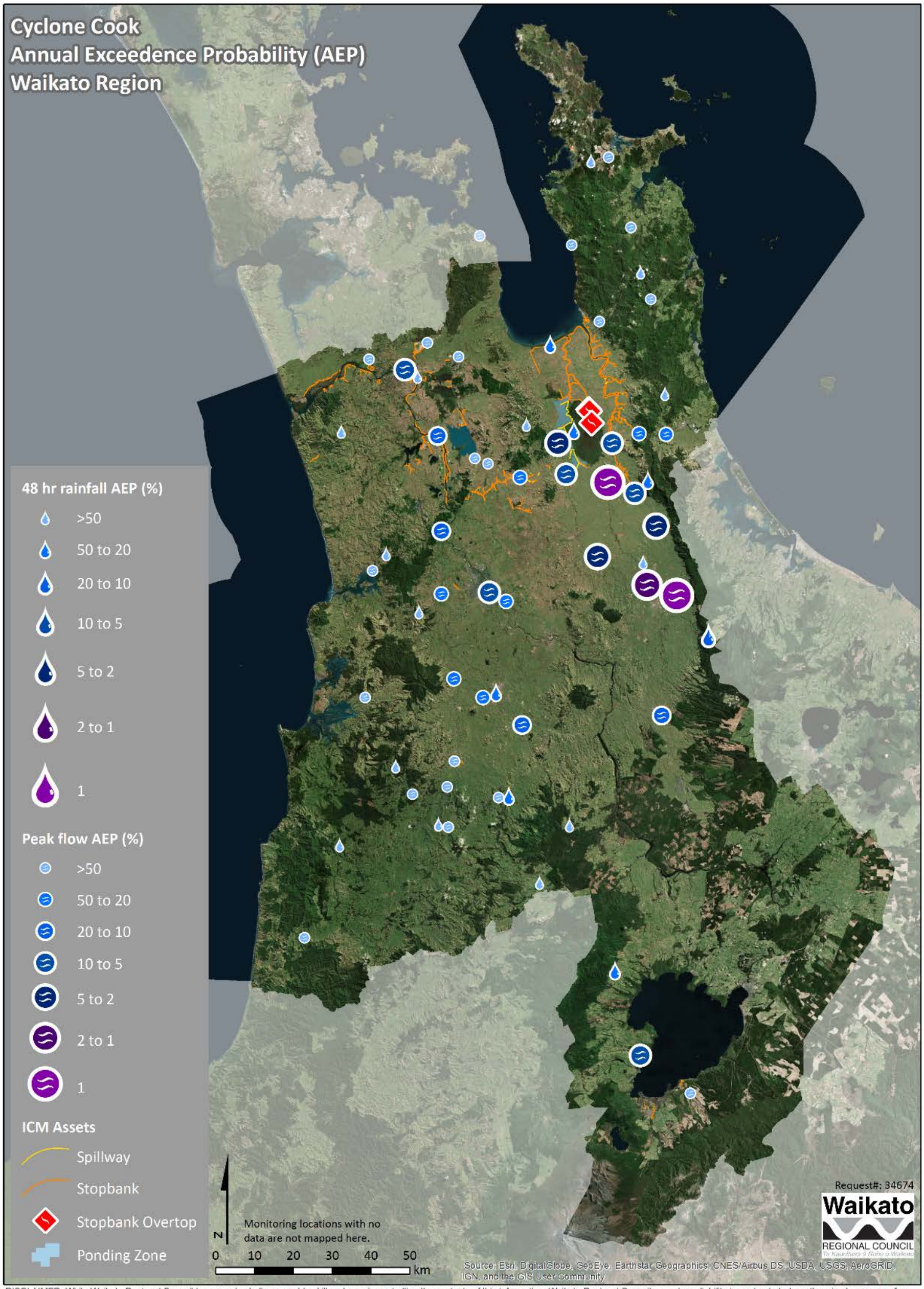

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Figure 10: 48 hour rainfall and peak river flow annual exceedance probabilities (AEP) during Ex-Tropical Cyclone Cook in the Waikato Region (see Table 21 for stopbank failure locations).

1.3 Monthly rainfall

The month of April 2017 was challenging from a flood management perspective as it is uncommon to have two ex-tropical cyclones affect New Zealand in quick succession as late in the cyclone season. Whilst rainfall totals recorded during Ex-Tropical Cyclone Cook were less than for the preceding events, the impacts on river levels were greater due to the cumulative effects (Figure 4 & Figure 10).

The cumulative effects of the successive events over a relatively short period need to be taken into account, as consideration as single events only results in an underestimation of catchment damage and scheme performance (Figure 11). This is particularly relevant as recovery from the March event was not complete in some areas (March Event report – Doc #: 10588909).

Over the month of April the majority of the region received on average, 247% higher rainfall than historic records (Table 4). Compounding this, the month of March was also unusually wet in many areas (Table 4). The prolonged period of high rainfall resulted in highly vulnerable catchments, saturated soils, and challenging flood management conditions due to high pre-existing river levels and decreased storage in flood protection scheme components. Rainfall levels were up to 450% of the normal March average and 317% of April averages. All sites (except April for Kaimai Summit) recorded greater than 100% of average rainfall for both March and April 2017.

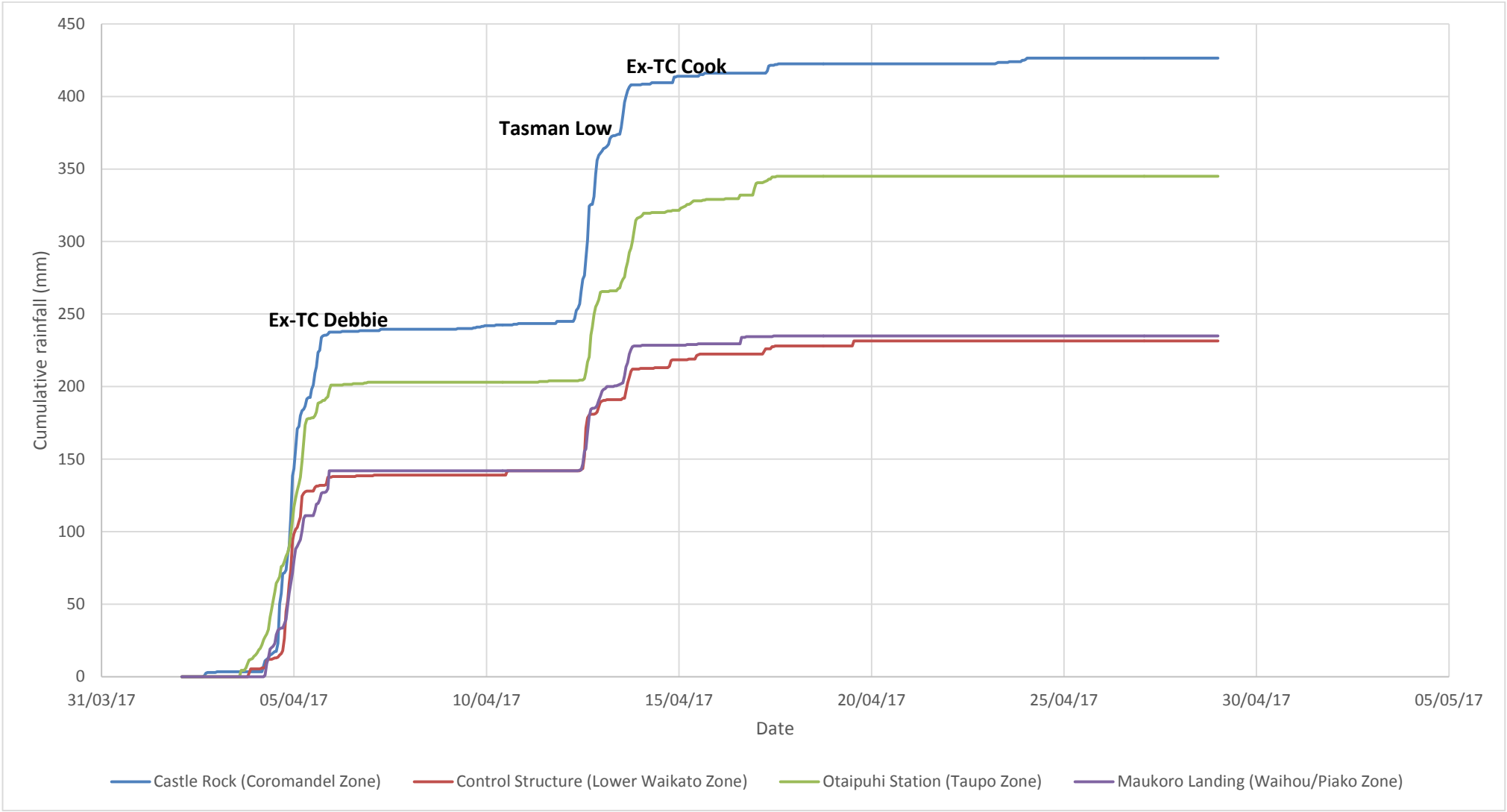

Figure 11: Cumulative rainfall totals across the region (4 selected sites with zone identified) representative of rainfall events during the month of April 2017.

Table 4: Monthly rainfall averages for March and April compared to 2017 levels, with 100-200% in blue, 200-300% in orange, 300-400% in red; and >400% in black.

Catch-ment	Location	Start of moni-toring	March 2017 rain-fall (mm)	March Ave. (mm)	% of ave. March rainfal l in 2017	April 2017 rain-fall (mm)	April Ave. (mm)	% of ave. April rain-fall in 2017	Mar/Ap 2017 rainfall (mm)	Mar/Ap Ave. (mm)	% of ave. Mar/Apr rainfall in 2017
Awaroa	Hauturu Trig	Mar-07	120	111	108	372	208	179	492	319	154
Kaawa	Waira-marama	Jan-07	277.5	86	324	287	119	241	564.5	205	275
Kaihere	Maun-gakawa	Dec-92	244.5	87	280	259	97	265	503.5	184	274
Kauae-ranga	Pinnacles	Mar-91	999	308	324	572	331	172	1571	639	246
Mangao-kewa	Te Kuiti EWS	Sep-83	154.5	78	198	271	100	271	425.5	178	239
Mangao-kewa	Wharekiri	Jun-89	180	96	187	282	126	223	462	222	208
Manga-otaki	Waitan-guru	Jun-89	158.5	134	119	410	181	226	568.5	315	180
Mata-wai	Hodder East Rd Castle Rock	Sep-90	525.5	174	302	477	201	238	1002.5	375	267
Ohine-muri	Queens Head	Nov-89	419.5	122	344	291	148	196	710.5	270	263
Otu-poto	Otaipuhi Climate Station	Oct-04	276.5	93	297	370	130	284	646.5	223	290
Piako	Maukoro Landing Rd	Oct-87	245	77	317	256	91	281	501	168	298
Piako	Appletree	Mar-11	333	148	225	265	124	214	598	272	220
Puniu	Bartons Corner Rd Br	Apr-03	219	61	357	276	103	267	495	164	302
Puniu	Ngaroma	Jun-82	231	137	169	380	155	244	611	292	209
Rapu-rapu	Kaimai Summit	Nov-92	500	486	103	167	211	79	667	697	96
Tami-hana	Matamata Aero	Feb-98	300	78	382	166	96	173	466	174	268
Waihou	Te Aroha	Jan-86	320	88	365	285	95	299	605	183	331
Wain-garo	Ruakiwi Rd Off SH22	May-02	214	75	285	219	108	202	433	183	237
Waipa	Otewa	May-81	191	95	200	299	109	274	490	204	240
Waite-kauri	Golden Cross	Oct-90	578.5	208	278	384	242	159	962.5	450	214
Waite-tuna	Karamu Walkway	Jan-07	270	97	278	262	126	207	532	223	239
Whanga-marino	Control Structure	Sep-03	364.5	81	450	249	78	317	613.5	159	386

1.4 MetService warnings and watches

Severe Weather outlooks, watches and warnings were issued by the MetService as well as information from NIWA and media organisations in the six days leading up to the events. The precise rainfall and wind intensities and locations associated with these weather systems were difficult to forecast accurately. This resulted in watches and warnings being put in place for large areas of the North Island for both events (Appendix 2). The amount of rainfall and its

spatial extent was particularly challenging to forecast for Ex-Tropical Cyclone Cook. Forecasting of amounts and distribution was more accurate for Ex-Tropical Cyclone Debbie.

1.5 River levels

The largest peak river flows were recorded on the Waitoa River (Mellon Road) and the Waihou River (at Okauia) during Ex-Topical Cyclone Cook (Figure 10). These both reached 1% AEP levels (100 year event). Followed by the Piako River (at Kiwitahi and Maukoro Landing) during Cook; and the Mangatangi (at Maramarua) and Whareroa (at the Fishtrap) Rivers during Ex-Tropical Cyclone Debbie, that all reached 5-3% AEP (30 to 50 year event) levels (Figure 4 & Figure 10). Peak river flow data is collated in Appendix 3.

Peak river flows triggered a number of alarms across numerous sites throughout both events (Appendix 4). The most notable of these were at Awakino (road closure of SH3), the Waikato River at Hamilton (1 m from inundation of Anne Street), Waikato River at Rangiriri (<1 m from SH1 spillway operation), and Ohinemuri River at Karangahake (0.3 m from stoplog deployment at Criterion Bridge, operations staff on standby).

The cumulative impact on river storage and scheme performance of the successive events that occurred during April is better represented by analysing river flow over longer periods (rather than just considering the peak). This work was undertaken by completing a flood frequency analysis using WISKI software (see Appendix 5 for methodology).

The calculated design flow values for sites at a given ARI (average recurrence interval) are also shown in Appendix 5.2 (results section, page 88). Due to the statistical method of calculating the ARI and AEP, 95% lower bound frequency of occurrence of the events are listed in Table 5. This shows that there is 95% confidence that the mean ARI of the observed event is greater than this (i.e., 95% of the time we would expect the ARI to be calculated as greater than this value). The 95 percentile minimum ARI values were calculated and then coverted to AEP. This shows that for sites along the Piako and Waitoa Rivers, there is 95% confidence that the mean AEP is less than 2.5% over 14 days (Table 5)

Table 5: Flood frequency analysis for April 2017 (95% confidence upper bound ARI and corresponding AEP), with red showing 5 to 1% AEP, orange 10 to 5% AEP, and yellow 20 to 10% AEP.

River	Location	72 hours		7 days		14 days		28 days	
		ARI (yrs)	AEP (%)	ARI (yrs)	AEP (%)	ARI (yrs)	AEP (%)	ARI (yrs)	AEP (%)
Mangaokewa	Te Kuiti	1.9	**52.6**	**1.8**	**55.6**	**2.3**	**43.5**	**1.7**	**58.8**
Waipa	Otorohanga	1.5	**66.7**	1.3	**76.9**	1.7	**58.8**	1.4	**71.4**
Waipa	Whatawhata	3.2	**31.3**	2.3	**43.5**	3.4	**29.4**	2.3	**43.5**
Waikato	Hamilton	5.6	**17.9**	5.2	**19.2**	7.0	**14.3**	5.2	**19.2**
Waikato	Ngaruawahia	6.2	**16.1**	5.2	**19.2**	7.6	**13.2**	5.4	**18.5**
Waikato	Control Structure	6.2	**16.1**	6.3	**15.9**	7.8	**12.8**	6.2	**16.1**
Piako	Paeroa-Tahuna Rd	33.0	**3.0**	25.0	**4.0**	40.0	**2.5**	18.0	**5.6**
Waitoa	Mellon Road	27.0	**3.7**	16.0	**6.3**	14.0	**7.1**	9.0	**11.1**
Piako	Maukoro Landing (WL only)	17.0	**5.9**	11.0	**9.1**	7.9	**12.7**	7.6	**13.2**
Ohinemuri	Karangahake	1.4	**71.4**	1.4	**71.4**	1.4	**71.4**	1.4	**71.4**
Waihou	Te Aroha	9.5	**10.5**	9.2	**10.9**	10.0	**10.0**	8.2	**12.2**

The mean AEP of the event showed the Waitoa River had a <1% AEP event over a 72 hour period, and a <1% AEP event also occurred on the Piako River over 72 hours and 14 days. Significantly for the Hauraki area, the Waihou, Piako, and Waitoa all experienced flows of <5% AEP over 7 days in April. Waikato River flows were also notable, reaching <10% AEP levels at Control Structure, Ngaruawahia, and Hamilton over 72 hour and 14 day periods (Table 6).

Table 6: Baseline ARI/AEP values for river flows over 72 hours, 7, 14, and 28 days (see Appendix 5 for methodology), with dark red showing <1% AEP, red 5 to 1% AEP, orange 10 to 5% AEP, and yellow 20 to 10% AEP.

River	Location	72 hours		7 days		14 days		28 days	
		ARI (yrs)	AEP (%)	ARI (yrs)	AEP (%)	ARI (yrs)	AEP (%)	ARI (yrs)	AEP (%)
Mangaokewa	Te Kuiti	2.6	**38.5**	2.3	**43.5**	3.2	**31.3**	2.2	**45.5**
Waipa	Otorohanga	1.9	**52.6**	1.6	**62.5**	2.2	**45.5**	1.7	**58.8**
Waipa	Whatawhata	4.9	**20.4**	3.3	**30.3**	5.1	**19.6**	3.3	**30.3**
Waikato	Hamilton	11	**9.1**	9.8	**10.2**	16	**6.3**	9.9	**10.1**
Waikato	Ngaruawahia	11	**9.1**	8.7	**11.5**	15	**6.7**	8.9	**11.2**
Waikato	Control Structure	14	**7.1**	15	**6.7**	21	**4.8**	14	**7.1**
Piako	Paeroa-Tahuna Rd	126	**0.8**	91	**1.1**	184	**0.5**	56	**1.8**
Waitoa	Mellon Road	225	**0.4**	71	**1.4**	52	**1.9**	23	**4.3**
Piako	Maukoro Landing (WL only)	98	**1.0**	41	**2.4**	20	**5.0**	21	**4.8**
Ohinemuri	Karangahake	1.6	**62.5**	1.6	**62.5**	1.6	**62.5**	1.6	**62.5**
Waihou	Te Aroha	24	**4.2**	24	**4.2**	27	**3.7**	18	**5.6**

1.5.1 Compared to recorded monthly data

Graphs of river maximums, averages, and minimums during March and April 2017, compared to monthly average levels over the length of records can be found in Appendix 6.

1.5.1.1 Waihou/Piako Zone

The Waihou River (at Te Aroha) recorded the highest April water level and equal highest flow (Figure 36 & Figure 37). It is likely that the highest flow was not recorded due to changes in river rating leading to a lower flow creating a higher river level. The maximum April 2017 water level was 1.4m higher than the usual April average, with the maximum 0.1 m above the previous highest level recorded since 1965.

In the Piako system, the highest April water levels and river flows were recorded at Paeroa-Tahuna Road (Figure 38 & Figure 39) and was only 0.1m from exceeding the maximum recorded level (records since 1972; Figure 38). At Maukoro Landing, the highest level recorded occurred during April 2017 (records since 1981, Figure 40), Similarly, the Mellon Road site (Waitoa River) also exceeded the highest water level and flow recorded (records since 1986; Figure 41 & Figure 42).

Average water levels in the Waihou/Piako/Waitoa systems for March and April were higher in 2017 (Figure 43 & Figure 44). However, the same extreme river levels and flows were not observed along the Ohinemuri River. Whilst levels necessitated the closure of the Karangahake Gorge for a short amount of time, they were not historically notable.

1.5.1.2 Lower Waikato Zone

At Mercer (Figure 45 & Figure 46) and Rangiriri (Figure 47 & Figure 48), the April 2017 average Waikato River level and flow exceeded all previous April maximums. However, flow and levels did not approach maximum ever recorded levels (July 1998). At Ngaruawahia, the April 2017 average (11.2 m) approached previous April maximum level (11.3 m), but did not exceed this (Figure 49). Whereas river flow at Ngaruawahia equalled the previous maximum recorded April flow (Figure 50).

1.5.1.3 Central Waikato & Waipa Zones

The Waikato River gauge at Hamilton, also showed April 2017 averages exceeded all previous April maximum water level and flow records (Figure 51 & Figure 52).

When compared to only April records, the April 2017 Waipa River flows and levels at Whatawhata exceeded previous maximums (Figure 53 & Figure 54). However, values were significantly lower than historic maximums recorded at other times during the year.

1.6 Flood extent mapping

Flood extent mapping will be undertaken once on-ground surveying of flood extent lines is completed. Field work is to be undertaken during May, focussing particularly on the Piako area. This will then be digitised using fulcrum points, GPS survey, LiDAR and satellite/aerial photographs. Once complete, this mapping will be integrated into Zone-scale reports.

1.7 Scheme specific reporting

The scope of this report focusses on the weather events and impacts at a regional scale. Specific reports pertaining to individual scheme performance will be undertaken as required (Table 7). Many of these are currently (as of June 2017) underway and will address scheme-specific issues in detail. As previously stated, the purpose of this report is to provide the rainfall and river level frequencies which can then feed into these more specific assessments.

Table 7: Scheme-specific reviews planned for Ex-Tropical Cyclones Debbie and Cook.

Report	Timeframe (as at end June 2017)
Piako Scheme Performance	Underway, as initiated by Zone manager. Awaiting on-ground survey data.
Kopuatai DOC Weirs Review	Underway
Hauraki (including Waihou)	Local flood event report including disaster funding requirements.
Waihou/Piako Flood Event Remediation	Underway
Lower Waikato Flood Event and Remediation	Underway

However, this report does include reference to the design levels of stopbanks and spillways. This is relative to the latest level of service review undertaken for that particular scheme (these are done on a 10 year cycle) and given as a percentage AEP values in the operations observations discussions (Section 6).

2 Comparison to previous significant flood events (1958 & 1998)

In July 1998 a significant flood event occurred, mainly impacting the Lower Waikato area. This followed heavy rainfall during 8-15 July and caused inundation in Hamilton, Ngaruawahia,

Huntly, Mercer, and rural areas along the Waipa River. Similarly to the April 2017 events, heavy rainfall also occurred the week prior to this leaving catchments saturated and vulnerable. Rainfall totals for the April 2017 event were less than for the 1958 (with Ngaroma the exception) and 1998 events (Table 8). This correlates with the less severe impacts reported in 2017, however there may also be areas with sparse telemetry (such as the Upper Piako) where rainfall levels may have exceeded those reported.

Peak river flows during the 1998 event were calculated to have a probability of between 2 and 1% AEP for the Lower Waikato system and the upper Waipa River, and 5% AEP for the upper Waitoa system (Munro 1998). Peak flows during the April 2017 event did not reach these levels in the Waikato and Waipa catchments (). For the Kauaeranga River the largest river flows were recorded during the March 2017 event, when the spillway at Thames operated twice in two days (see March event report Doc #: 10588909). The largest magnitude flow event for the Waihou, Waitoa, Piako, and Ohinemuri Rivers occurred during the Ex-Tropical Cyclone Cook events (Table 9), despite rainfall totals being less than during historic events (Table 8). As discussed in previous sections, this demonstrates the cumulative impacts of two Ex-Tropical Cyclones within 12 days as well a high rainfall month preceding.

Table 8: Rainfall figures for the February 1958, July 1998 (from Munro 1998), and April 2017 events, highlighted red where April 2017 event is larger than monthly or weekly totals from 1998 or 1958.

Rainfall Site	Catchment	Month total: February 1958 (mm)	Month total: April 2017 (mm)	Week total: 8-15 July 1998 (mm)	Week total: 3-9 April 2017 Ex-TC Debbie (mm)	Week total: 10-16 April 2017 – Ex-TC Cook (mm)
Mangatangi	Mangatangi	-	333.0	316	184.5	108.5
Maungakawa	Mangawara	325	182.0	202	98.0	56.5
Ruakura	Waikato	324	251.4	191	109.0	102.8
Otewa	Waipa	-	298.5	196	130.5	129.5
Ngaroma	Waipa	340	381.5	361	138.0	168.0
Te Kuiti	Mangaokewa	-	265.0	260	129.0	90.5
Pinnacles	Kauaeranga	-	569.0	460	250.0	219.0
Golden Cross	Ohinemuri	-	381.5	273	112.5	245.0
Maukoro Landing	Piako	-	255.5	172	142.0	87.5
Te Aroha	Waihou	-	284.0	150	123.0	138.0
Kaimai	Waihou	-	482.5	370	170.0	267.0
Waitanguru	Awakino/Mokau	-	403.0	286	214.5	102.5
Turangi	Tongariro	-	237.6	195	126.0	67.6

Table 9: Peak river flows for February 1958, July 1998 (from Munro 1998), and March 2017, compared to April 2017 events, gradient red colour shows relative size across the four events.

		Peak River Flows (m^3/s)				
Site	**River**	**February 1958**	**July 1998**	**March 2017**	**Ex-TC Debbie (April - 17)**	**EX-TC Cook (April - 17)**
Te Kono	Tauranga-Taupō	-	218	59.8	207.1	75.9
Rauroa SH3	Awakino	-	282	34.2	247.2	56.8
Te Kuiti	Mangaokewa	-	122	24.1	76.6	53.3
Otorohanga	Waipa	625	418	90.3	220.5	177.9
Whatawhata	Waipa	1130	776	284.4	598.0	470.6
Hamilton	Waikato	905	807	430.7	669.7	678.7
Ngaruawahia	Waikato	1482	1491	698.7	1094.0	974.7
Rangiriri	Waikato	-	1490	722.4	1157	1059
Mercer	Waikato	1260	1575	828.5	1231	1214
Okauia	Waihou	-	180	96.2	30.2	329.6
Te Aroha	Waihou	-	190	126.7	142.0	360.2
Waharoa	Waitoa	-	25	19.3	38.4	54.5
Mellon Road	Waitoa	-	68	14.7	67.8	139.3
Kiwitahi	Piako	-	72	5.4	26.1	89.9
P-T Road	Piako	-	168	41.5	171.3	189.5
Smiths	Kauaeranga	-	353	910.8	172.7	139.9
Karangahake	Ohinemuri	-	295	434.9	178.2	504.4

3 Relevant WRC flood protection schemes

3.1 Waihou/Piako Zone

The Waihou Valley Flood Protection Scheme was built in the 1980's to 1990's and comprises 175 km of works including stopbanks, 20 pumpstations, 75 floodgates and drainage control works. The purpose of the scheme is to protect agricultural land in the zone between Te Aroha and the Firth of Thames, stabilise channels in the area from Te Aroha south, and provide protection to urban areas of Thames, Paeroa, and Te Aroha (Basheer 2002).

The Waihou flood protection begins at Te Aroha where the western bank provides 1% AEP level protection, in order to prevent the Waihou flowing across the plains and joining with the Piako River. Immediately downstream of Te Aroha there are stopbanks on both sides of the river providing a lower standard of protection (mostly 10% AEP design standard). At the southern outskirts of Paeroa the protection levels increase back to 1% AEP levels along the Waihou and the confluence of the Ohinemuri River. Numerous other tributaries are stopbanked at a 10% AEP standard, with the exception of the Hikutaia and Kirikiri Streams which are at 2% due to nearby urban areas requiring protection. This protection continues until the Waihou drains into the Firth of Thames (Peploe et al. 2011).

The Piako River Scheme was primarily built in the 1960's and 1970's, with some single components built prior to this and later incorporated into the scheme. It is comprised of 166 km of stopbanks, 59 floodgates, and 32 pumpstations (Peploe et al. 2011).

The Piako flood protection is more complex than the Waihou, owing to its relationship with the Kopuatai peat dome and its emergency ponding areas. The protection begins at Paeroa Tahuna Road and runs along both sides of the river to the Waitoa River confluence. Here, the stopbanking ends on the eastern side (true right bank) but continues to the west (left bank) until the Elstow canal joins the Piako on the eastern side. Between the Waitoa River and the Elstow Canal are a series of ponding zones running along the western side of the Kopuatai peat dome. These ponding zones are shown in Figure 12 and can be divided into four main types: 1)

uncontrolled ponding areas where water can freely pond immediately along side the peat dome; 2) an initial ponding area that is flooded relatively frequently; 3) the first emergency ponding zone that will be inundated when flows approach 10% AEP levels and the stopbanks in this area begin to spill; and 4) the second emergency ponding zone which will have water spill into it when flows approach 5% AEP levels.

The flood protection assets to the north of the ponding zones provide 1% AEP level protection for both Piako River flood flows and tide levels. Foreshore stopbanks bounding the Firth of Thames are all designed to 1% AEP levels.

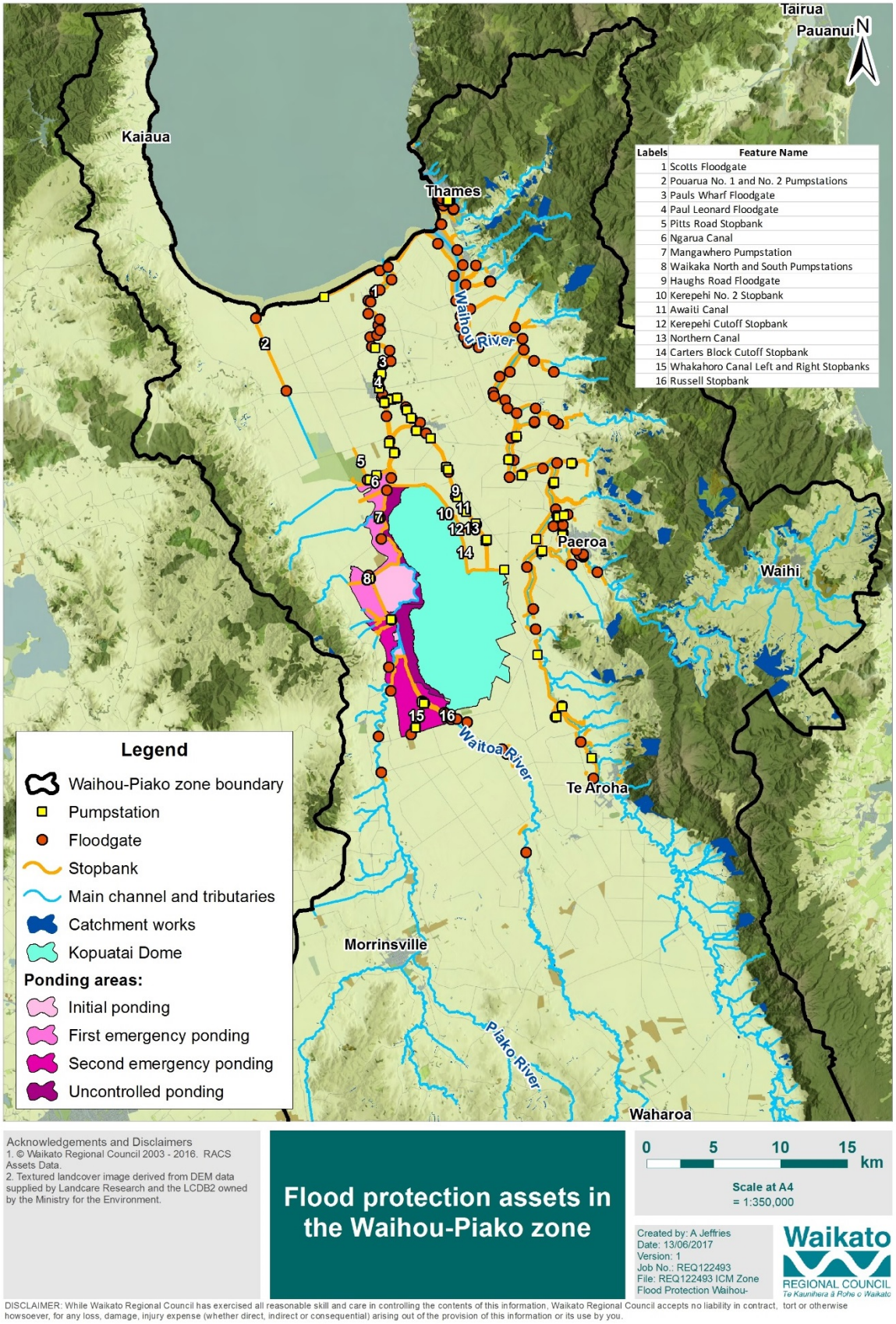

Figure 12: Flood protection scheme components discussed in Waihou/Piako Zone April event observations.

3.2 Lower Waikato Zone

River flood flows in the Lower Waikato Zone are dependent on flows from the Upper Waikato (partially managed by the nine hydro-dams that are part of the Waikato Hydro Scheme, see Section 5) and the Waipa River (uncontrolled, low gradient, confluence at Ngaruawahia). The Lower Waikato flood protection works are comprised of 250 km of stopbanks, 63 pumpstations, 247 floodgates, and numerous other river works (Figure 13).

Stopbanks along the main Waikato River channel south of Rangiriri are of a 1% AEP design standard, with 600 mm freeboard through Huntly and 300 mm freeboard between Huntly and Rangiriri. Protection on both sides of the river between Rangiriri and Te Kohanga is at 5% AEP level with 600 mm freeboard. At Te Kohanga on the southern side (left bank) and part of Aka Aka on the northern side (right bank) is designed to provide 1% AEP protection with 300 mm freeboard.

There are also flood protection structure outside of the main Waikato River channel. These range from 1% AEP design (Lake Waikare and Whangamarino from Waikato River), 2% AEP design (Mangawara River), and 5% AEP design (Ruawaro and Deroles from Lake Whangape; Mangatawhiri River downstream of SH2), and 14% AEP (Mangatawhiri River upstream of SH2) (Peploe et al. 2011b).

Numerous drainage compartments are also in place across the Lower Waikato Zone. These provide land drainage for agriculturally productive land and most are designed to allow for the drainage of ponded water after a 10% AEP rainfall event within three days (Figure 13).

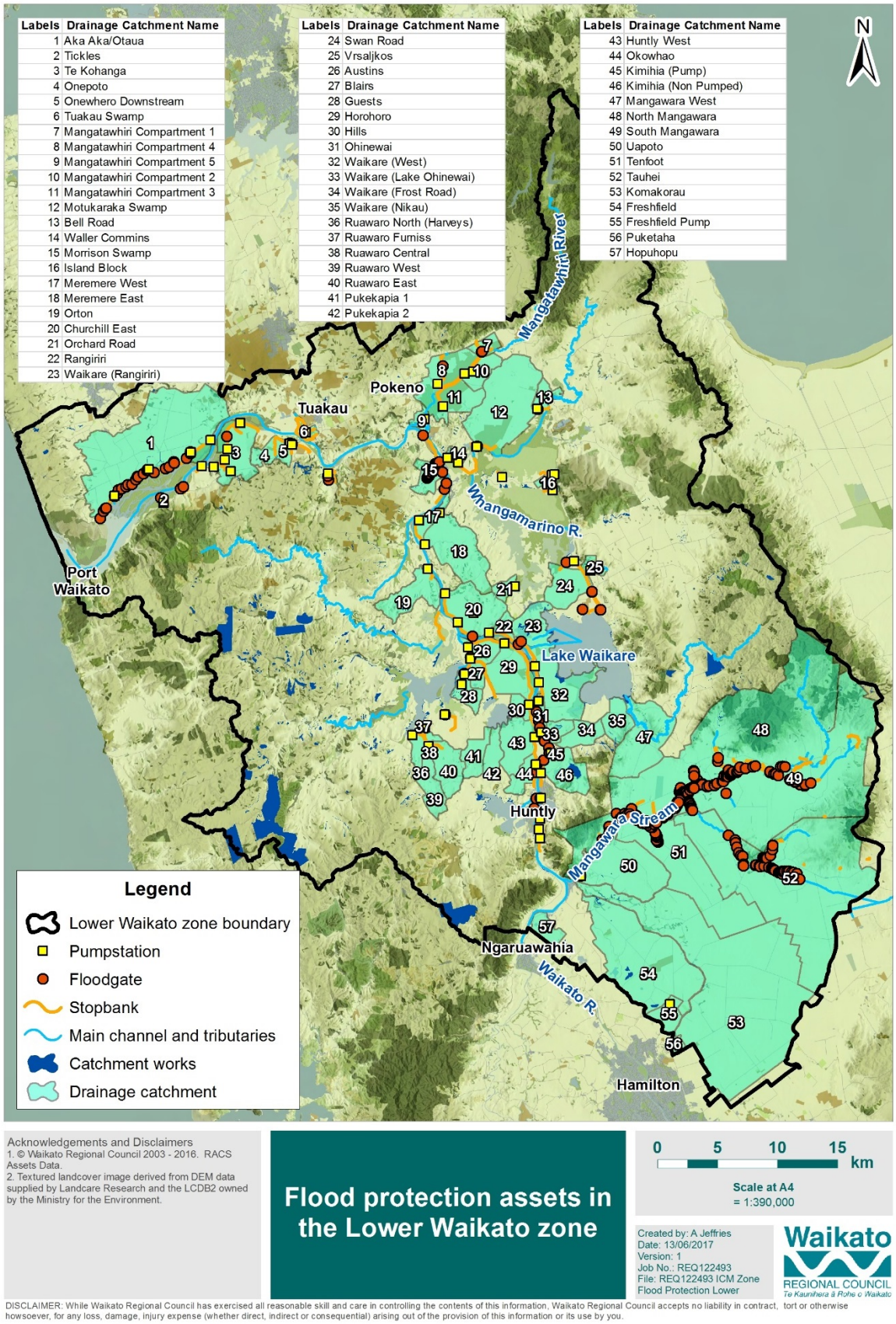

Figure 13: Flood protection scheme components and drainage schemes discussed in Lower Waikato Zone April event observations.

The Lower Waikato Control Scheme (Figure 14) offers protection to the Lower Waikato Zone downstream of Rangiriri. The scheme diverts water from the Waikato River into Lake Waikare and the Whangamarino Wetlands during times of high flow. The scheme provides storage when Waikato River flow exceeds 2% AEP levels. The level of Lake Waikare is regulated through an outlet canal with gates allowing drainage into the Whangamarino Wetland. Control

structures at the Rangiriri spillway between the Waikato River and Lake Waikare ensure that during non-flood events the lake level remains slightly below where it naturally would be. Then during times of high flow water uses the spillway to flow into the lake. As Lake Waikare fills there is less pressure on stopbanks along the Waikato River, further reducing the chance of substantial flooding in the northern part of the Lower Waikato Zone.

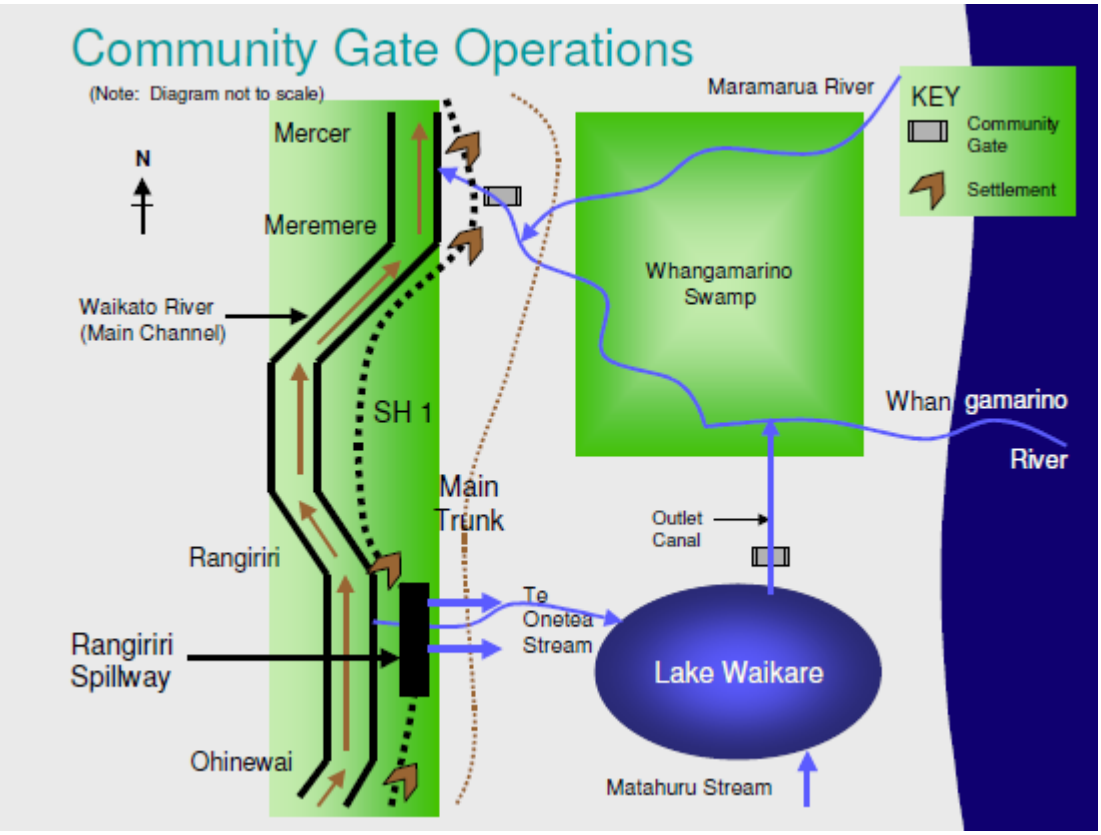

Figure 14: Conceptual diagram of the Lower Waikato Control Scheme.

March and April are normally months when flood scheme maintenance is undertaken, being prior to the wet winter months and post summer cyclone season. This is usually the time when complete pump overhauls are scheduled. Unfortunately, 2017 did not follow the usual pattern and some areas became potentially vulnerable due to the scheduled maintenance. However, at the time only one pump was being completely overhauled. The Meremere Main pumpstation has four pumps with three being operational at any given time. Despite the duty pump being removed the other three remained operational, and the level of service was met. Another pumpstation required minor repairs in the time between the March and April events (Table 10).

Table 10: Logged pumpstation maintenance in progress in the Lower Waikato at the time of the April events.

Asset description	Action type	Action description	Start date	Completion date
Hills pumpstation - Pump 1	Un-scheduled	Pump Maintenance - Repair under $2000	31/03/2017	28/04/2017
Meremere Main pumpstation - Pump 1	Scheduled	Pump Renewal - Overhaul	1/03/2017	26/04/2017

4 Regional Flood Response

4.1 Regional Flood Response Management Plan

The Regional Flood Response Management Plan (RFRMP) is a document that informs and directs the management and coordination of WRC staff responding to a flood event. It sets out the roles and responsibilities for staff, transition steps moving into response and through to remediation, trigger points for determining the scale of the event (Section 4.2), and the flood debrief and reporting process.

One of the key functions described is the interaction between the Local Coordinators (Zone or Section Manager), and the Regional Flood Response team (involving key rostered staff). Figure 15 shows how these roles interface with each other, Civil Defence, the WRC Governance Group, and WRC local office operations staff (based in Whitianga, Paeroa, Te Aroha, Gordonton, and Taupō).

4.2 Determination of flood scale and severity

Determining the scale of a flood event is a key part of the critical path for matching resourcing and providing structure as part of response. The likely event and flood response scale is formally declared at the beginning of a response to give time for planning and operational response, and to allow WRC to communicate on the likely extent and severity of the event. Scale is also relevant to forward planning for remediation activities.

The council operates a three tier system based on geographic spread to define the scale of the flood response required and the likely resourcing that is likely to be required. A summary of each scale is as follows, with further detail in Table 11:

1. Event can be dealt with within existing resources of local office team (regional team monitoring and on standby), developing situation coordinated locally.
2. Capacity and capability of local office team starts to become stretched but event is still managed locally with regional response team oversight (i.e. regional team is activated in support).
3. Flood event extends beyond capacity of the local response team/office and event is now fully coordinated/managed by the regional flood response team.

Table 11: Flood event scale indicators

Scale	Type of event	Area offices directly involved in flood response	Resource requirements	Example funding thresholds (indicative)
1	Local event	One area office	Low	Absorbed into existing operational budget 1 in 20yr flood
2	Subregional event	Two area offices	Medium	Regional Fund 1 in 20-50yr flood
3	Regional event	Two or more areas offices	High	National Fund 1 in 100yr flood

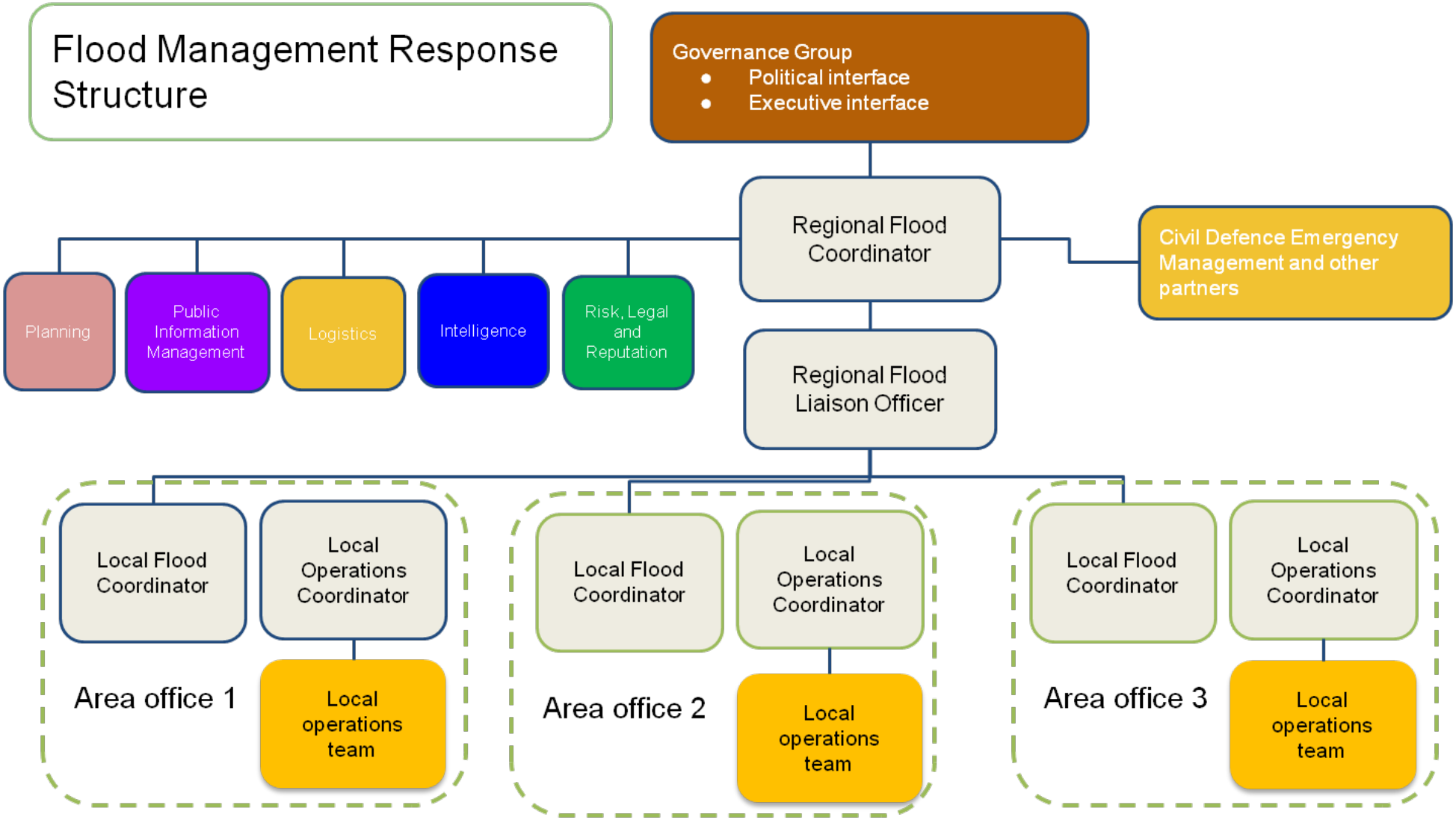

Figure 15: Flood response management structure described in the RFRMP (WRC Technical Report 2016/01), using three affected area offices as an example.

4.3 April 2017 response

Based on the RFRMP, the event reached a Tier 2 response during both events. This was due to two or more areas being activated, primarily Lower Waikato, Waihou/Piako and Coromandel Zones, and it was thought that the rainfall levels would likely exceed 1 in 100 year ARI (or 1% AEP) event during Ex-Tropical Cyclone Cook. If the rainfall initially forecast with Ex-Tropical Cyclone Cook had occurred it is likely that the Tier 3 trigger points would have been reached.

The Regional Flood Response team acted in support of local office teams as required. The support was predominantly through providing information, rainfall and river level forecasts where available, and high flow management of the Waikato Hydro Scheme in conjunction with Mercury and Genesis Energy.

5 Waikato Hydro Scheme and High Flow Management

5.1 Background

5.1.1 Waikato Hydro Scheme

The Waikato River is the longest in New Zealand at 425 km long and has a catchment area of 14,258 km^2. Both the Lake Taupō and lower Waikato River catchments are highly modified. There are currently eight dams in the Waikato River which are currently managed by Mercury Energy. Lake Taupō provides 93% of the Waikato hydro system storage with total storage in the eight hydro dams amounting to only 7% of the total storage (Figure 16).

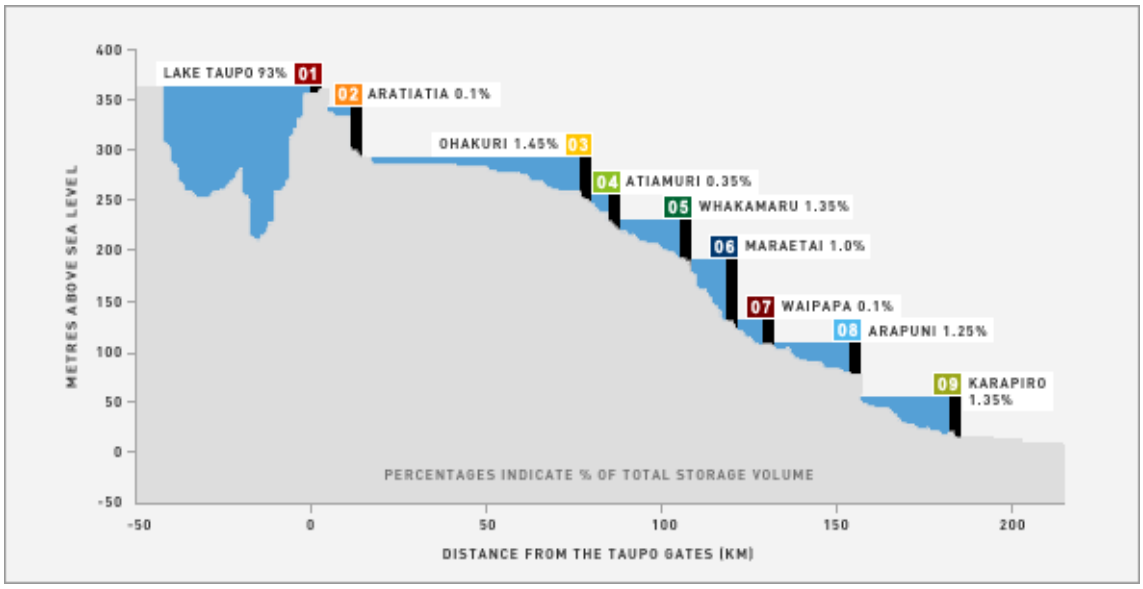

Figure 16: Graph showing the 8 Waikato Hydro-dams (plus the Lake Taupō Gates, their location, elevation, and relative storage capacity (taken from: https://www.mercury.co.nz/About/Renewable-Energy/Hydro-Generation.aspx)

The status of Lake Taupō and its tributaries affect management of the entire Waikato River with flow of the Waikato River downstream of Karapiro Dam dependent on the operating regime of the Waikato River hydro scheme managed by Mercury Energy.

5.1.2 High flow management plan

The granting of the Mighty River Power (MRP) (now Mercury Energy) resource consents in 2006 requires MRP to develop a high flow management plan (HFMP) to describe how the Waikato hydro system would be managed during high flow conditions.
The plan is required to demonstrate:

- How the hydro system will be operated to meet dam safety requirements.
- How the system will be operated to limit the adverse effects of a flood including the effects on Lake Taupō, the hydro reservoirs and the Waikato River downstream of Karapiro.
- How Mercury Energy will assist the Waikato Regional Council (WRC) in its role as flood coordinator.

The objectives of the HFMP are to:

- Ensure that roles and responsibilities are clear and understood between WRC and Mercury Energy.
- To monitor tributary inflows in the Waikato hydro scheme catchments during times of high flow.
- To ensure that communication protocols are clear between WRC, Mercury Energy, and external parties.
- To ensure that information on catchment and river flows during high flow events is transparent to WRC.
- To ensure Mercury Energy complies with all resource consent conditions.

5.1.3 High flow phases

High flow management plan (HFMP) comprises three phases that provide guidance on decision making by WRC in conjunction with Mercury Energy and Genesis Energy. The three phases in the HFMP are:

5.1.3.1 Phase One

Phase 1 is an early warning discretionary phase. Allows the reservoirs to be drawn down in advance of a forcast storm in the catchment predicted by weather forecast data supplied by MetService. Triggers for Phase 1 are:

- The flow in the Waikato River at Ngaruawahia exceeds 650 m^3/sec OR
- Lake Taupō water level exceeds 357 m above sea level OR
- One or more flood table discharge levels (FTDL) are likely to be exceeded AND
- High flows are anticipated

5.1.3.2 Phase Two

Phase 2 is usually entered into when rainfall that has been forecast starts falling. Phase 2 provides for actions to be taken during heavy rain or flood events to limit the effect of flooding. Triggers for phase 2 are:

- The flow in the Waikato River at Ngaruawahia exceeds 1000 m^3/sec OR
- Lake Taupō levels exceed 357.25 m above sea level OR
- One or more FTDL are likely to be exceeded AND
- High flows are anticipated

5.1.3.3 Phase Three

Phase 3 is entered when three or more power stations FTDL are exceeded. When three FTDL are exceeded outflows from Lake Taupō must be reduced to 50 m^3/sec.

5.2 April 2017 event

The weather leading up to 4 April 2017 comprised of a series of region wide high volume rainfall events keeping the catchments saturated with very little capacity for retention that would slow runoff. There was still capacity in the river systems for increased flows but some key flood management storage areas were already exceeding the normal seasonal water levels/storage (higher than normal Lake Taupō water level).

Projected weather systems for April provided challenges in operation of the Waikato system where lake levels were already high and catchments saturated. Preceding events during the summer had left the following legacy:

1. The projected weather events would occur on already saturated catchments.
2. The end of the cyclone season (April) normally coincides with seasonal lower lake levels at Taupō. Lake Taupō levels were unusually high coming out of summer but within consented range. Previous dry summers left water levels low providing capacity in Lake Taupō to absorb inflows and provide flood storage. However, the summer of 2016/17 was much wetter than normal. This anomaly had been noted prior to the event. Low rainfall summers had facilitated storage capacity in the past by coincidence rather than prudent flood preparation management (Figure 17).
3. Lake Waikare had exceeded the operating range by the start of the April event due to previous high rainfall events in its catchment. The discharge gate would continue to be open for the entirety of the event. This left a component of the Lower Waikato flood storage scheme unable to be fully utilised during this event (see Section 4.1.2).
4. The antecedent conditions effectively removed two flood management storage areas (Taupō and Waikare) prior to the event.

These past events and the inherited status of flood storage tools added to the heightened interest on any potential impacts of the event.

Despite these issues, effective management of the Waikato Hydro Scheme significantly lowered the flood peak at Karapiro. The peak for Ex-Tropical Cyclone Debbie was 611 m^3/s, however modelling showed that under unmanaged conditions the peak flow would have been approximately 830 m^3/s (Figure 18).

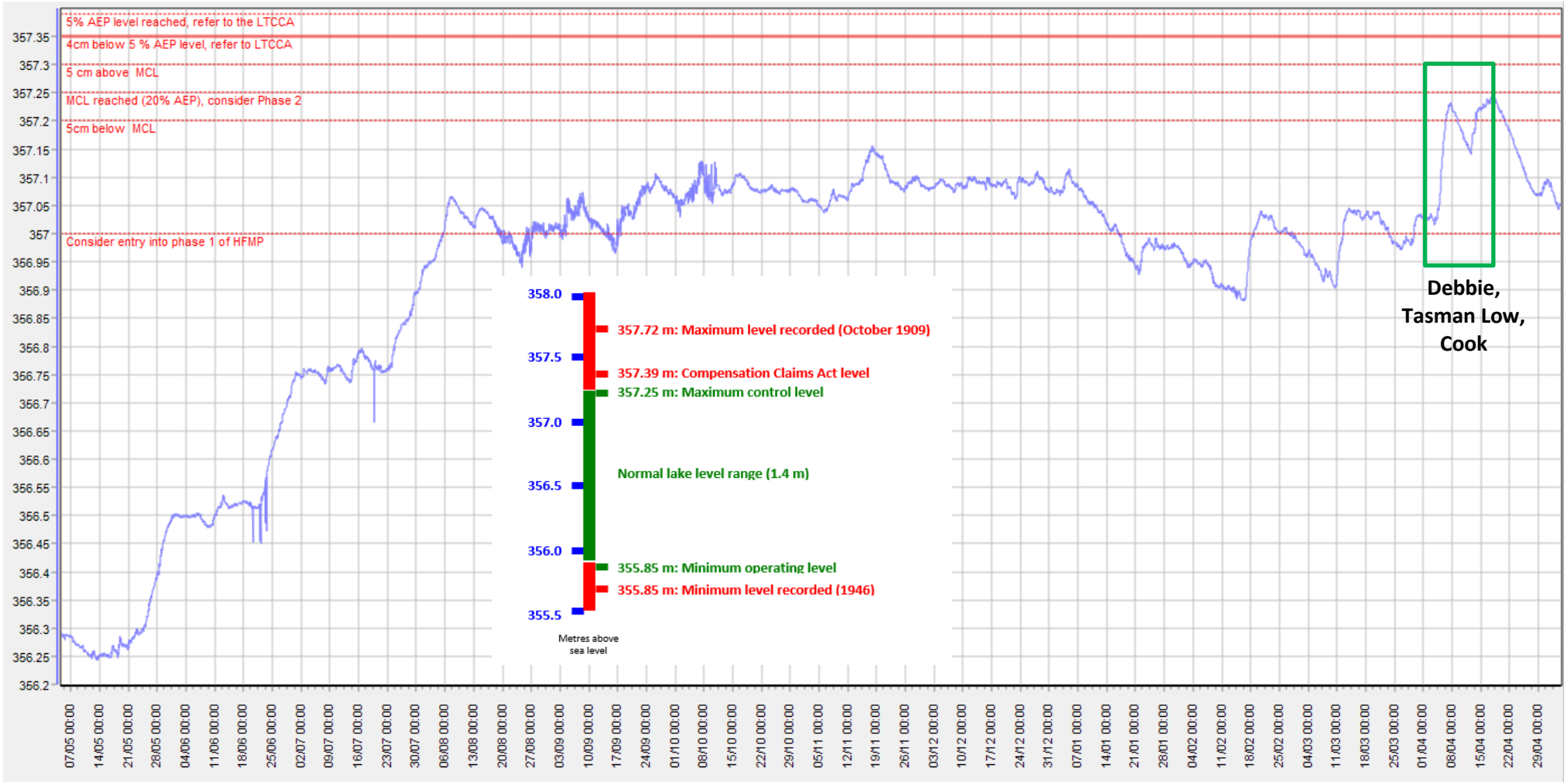

Figure 17: One year (2016/17) of Lake Taupō levels (in m RL), showing significantly higher lake levels than at the same time last year, with inset showing minimum, normal and maximum levels.

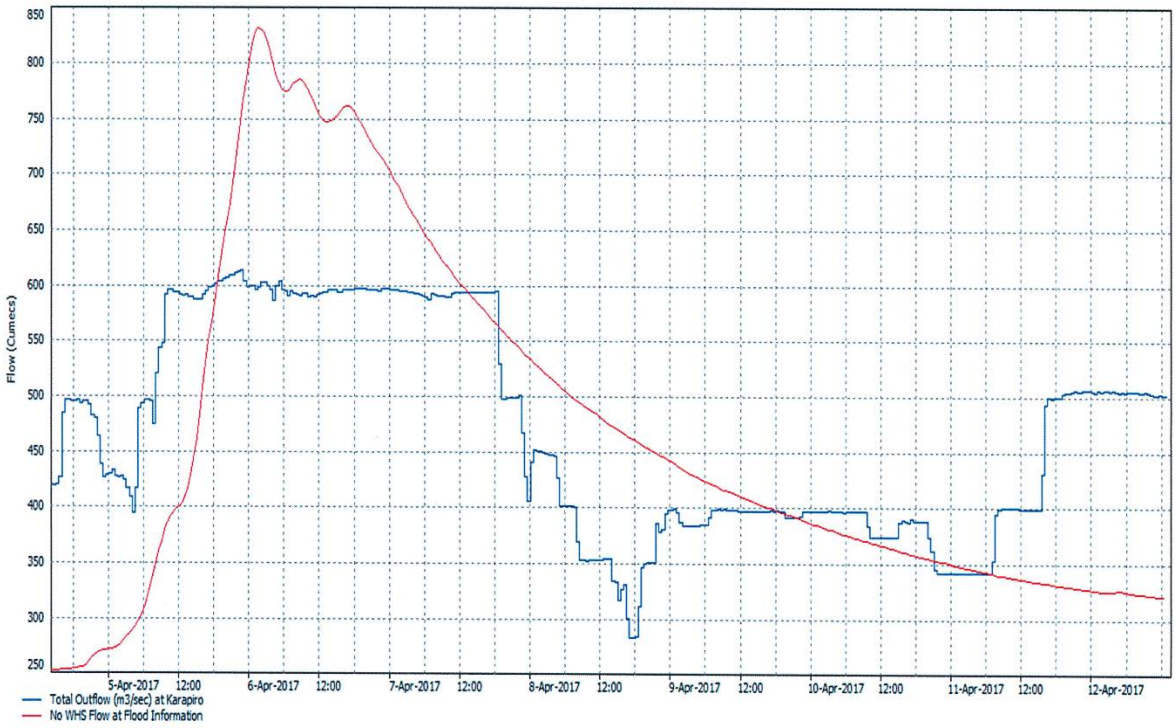

Figure 18: Graph of total Karapiro outflows with the Waikato Hydro Scheme (blue) and without (red).

5.2.1 Ex-Tropical Cyclone Debbie impacts

5.2.1.1 4 April

Phase 1 flood management entered into formally with Mercury. Tributary inflows had not started increasing and were running at 140 m^3/s. Due to the water level in Lake Taupō (RL 357.12m early in the day) and projections of possible lake levels it was agreed that the Taupō gate would be opened to discharge 300 m^3/s (maximum outflow) for as long as possible to provide as much storage as possible to absorb flood inflows in the lake. By mid-afternoon the tributary flow upstream of the Karapiro dam was increasing and Mercury expressed a desire to increase releases from Karapiro to 600 m^3/s with the prospect of reducing flows later. Releases from Karapiro were running at 402 m^3/s and expected to increase to 500 m^3/s. At Ngaruawahia flows were 379 m^3/s with Whatawhata contributing 66 m^3/s at that time. Mercury had good hydro scheme storage and was looking to maintain this throughout the night whilst also running high outflows from Lake Taupō to mitigate rising lake levels. By 1730 hours Taupō had risen to RL 357.40 m with the hydro tributaries starting to show significant increase in flow. Karapiro was discharging 420 m^3/s at this time with the prospect of increasing this to 600 m^3/s to compensate for increasedinflow within the hydro scheme.

5.2.1.2 5 April

The Taupō gate was still fully open discharging 300 m^3/s to control Taupō and water levels that were rapidly increasing due to record tributary inflows into the lake. Releases from Karapiro were maintained at 500 m^3/s through the night and increased to 540 m^3/s in the morning to pass as much water past the Waipa/Waikato confluence before flow in the Waipa peaked. At this stage Genesis Energy had not been contributing any foreign inflow (that is diverted water than would otherwise flow to the south but flows into Taupō for electricity generation purposes) to Lake Taupō due to maintenance on their tunnels.

Karapiro was discharging 600 m^3/s after Mercury were directed by the WRC Regional Flood Coordinator (RFC) to increase releases from the dam. The increased flow out of Karapiro provided storage to attenuate releases to the Lower Waikato when inflow increased. If direction had not been given early on and Mercury waited until forced by consent requirements releases would have been much higher than 600 m^3/s.

5.2.1.3 6 April

Phase 2 was entered into on 6 April as the flow at Ngaruawahia exceeded 1000 m^3/s. The weather forecast further heavy rain in the catchment and Taupō had already reached RL 357.20 m.

5.2.1.4 7 April

Flow from the hydro tributaries was contributing 380 m^3/s to flow in the river. Discharge at Taupō gate was reduced to 150 m^3/s because according to Mercury the tributary inflow downstream of Lake Taupō was the highest since 1964 and storage within the scheme was under pressure. There was a concerted effort to stay out of the prescriptive Phase 3 to avoid the uncontrolled discharges that are required under this phase. Flow from Taupō gate was increased in increments back up to 300 m^3/s through the day, with releases from Karapiro maintained at 500 m^3/s. Genesis Energy was contacted and advised of the prospect of turning out diversions (i.e., ceasing the flow of foreign water into Lake Taupō) if current and forecast lake level trends eventuate.

5.2.1.5 8 April

Mercury advised that the tributaries appear to be contributing less flow than the model predicted. Therefore, Karapiro flows were able to be reduced to 400 m^3/s, as storage increased and Ngaruawahia flows dropped below 1000 m^3/s.

5.2.1.6 9 April

By 9 April, flows in all river systems were now receding from their peaks. The long range forecast showed Ex-Tropical Cyclone Cook was heading towards New Zealand.

5.2.2 Tasman Low and Ex-Tropical Cyclone Cook impacts

5.2.2.1 14-15 April

With showers continuing Karapiro outflows were increased to 550 m^3/s. Mercury was requested by WRC to reduce the Karapiro outflows to 500 m^3/s. At midnight on 14 April, direction was given to Mercury to shut the Taupō gate in 50 m^3/s increments to match the increase in inflow from the tributaries to maintain the dam equilibrium and avoid uncontrolled discharges should water levels in the dams reach Flood Table Discharge Levels. This direction was given after discussion with Mercury and at their request in a bid to manage their hydro system to avoid flood table discharges and/or then move into phase 3 response.

WRC continued discussions with Mercury as there was concern at the amount of pressure the Lower Waikato defences were experiencing with the prolonged rainfall. Water levels in Lake Taupō were still elevated (RL 357.228 m and slightly rising) due to natural inflows. The Taupō gate was discharging at the maximum of 300 m^3/s. Mercury agreed to reduce Karapiro outflow to 500 m^3/s. While this would not be evident on that day it would relieve pressure in the next few days if the Waipa responded to the forecast rainfall. Mercury was also briefed of the possible need for Karapiro discharge to be reduced further.

Constant bands of rain were keeping flow in the hydro system tributaries elevated and forcing high discharge rates from Karapiro to continue.

Regional Flood Coordinator concerns at the time were:

- Pressure on the Lower Waikato and the future integrity of flood protection assets and likelihood of failures with prolonged soakage (after liaising with technical/operations staff).

- If it was deemed that there may be issues with flood protection assets, one option was to relieve pressure on Lower Waikato stopbanks by instructing Mercury to shut the Taupō gate (and thus reduce Karapiro outflows). However, this would have led to water levels in Lake Taupō, exceeding the Maximum Control Level.
- It was noted that it would take 1 or 2 days for the decrease in Karapiro flows to migrate down to the Lower Waikato, therefore a decision to reduce Taupō/Karapiro flows would have to be made quickly.

It was fortunate that the predicted rainfall did not eventuate and that the western catchment did not elevate flow in the Waipa again.

5.2.2.2 16 April

Mercury were informed by WRC to that an increase in outflow from Karapiro to 550 m^3/s was possible if needed. This was due to feedback from the operations team regarding the Lower Waikato assets indicating that the stopbanks were coping well and were not at threat of over topping or breach. However, Mercury were comfortable to leave the outflow at 450-500 m^3/s and indicated they were be able to reduce further as the tributary flow was predicted to decrease.

5.2.2.3 17 April

Releases from Karapiro flow were now at 450 m^3/s but were raised to 500 m^3/s as the focus shifted to decreasing Lake Taupō levels. Releases from Taupō gate continued at maximum outflow (300 m^3/s).

Genesis Energy requested to divert water once again into Lake Taupō. Modelling results showed there was minimal risk of the lake level rising again. WRC requested that Genesis Energy wait before diversions into Taupō resume until the lake showed a steady decrease in level as tributary inflows reduced.

5.2.2.4 18-19 April

During this time Genesis Energy diversions were brought back in a staggered fashion. WRC advised that as Lake Taupō level was continuing to drop normal operations could be resumed.

5.2.2.5 20 April

Due to the positive weather outlook and reduced catchment flows, the decision was made to move from Phase 2 and into Phase 1. The rationale around this was as follows:

- Lake Taupō Level below RL 357.25 m and falling (RL 357.207 m at 0800 hours), with Genesis Energy diversions no longer turned out.
- Tributary inflows were decreasing.
- Waikato River Flow at Ngaruawahia below 1000 m^3/s.
- Water levels in the Waikato River were receding downstream.
- Favourable weather outlook.

5.2.2.6 27 April

Due to the ongoing draining of all of the systems throughout the region it was decided to move out of Phase 1 as the majority of parameters met de-escalation criteria. The weather forecast at the time was the only criteria out of specification as rain was due in a few days but was not forecast to be significant.

6 Operations observations and event impacts

6.1 Primary lifeline issues in the Waikato Region

Both of the events caused road closures across the region (Appendix 7). The first major roading impacts of the event occurred during Ex-Tropical Cyclone Debbie at Mokau due to flooding and nearby slips. Numerous relatively small scale slips also occurred around the Taupō to Turangi road. Areas along SH 25 between Thames and Coromandel town, that had experienced slips during the March event (Tasman Tempest), were again closed due to slips during both Ex-Tropical Cyclones Debbie and Cook. Widespread surface flooding occurred across the region during both events causing numerous sections of road to require extreme caution, particularly across the Waihou/Piako Zone.

Flooding led to the evacuation (voluntary) of a small number of non-rural houses in the region. The locations, timing and number of properties affected are presented in Table 12.

Table 12: Property damage reported in the Waikato Region during the April events.

Location	Number/Type	Cause	Date
Ex-Tropical Cyclone Debbie			
Whangamata	4 houses	Surface Flooding	AM 5 April
Whangamata	6 houses	Surface Flooding	PM 5 April
Morrinsville	1 basement and garage	Surface Flooding	PM 5 April
Waihou	1 basement	Flooding	PM 5 April
Waitoa	Converted garage	Flooding	PM 5 April
Morrinsville	1 house	Flooding	AM 6 April
Tasman Low and Ex-Tropical Cyclone Cook			
Te Aroha	2 houses 2 basements/garage	Flooding	PM 13 April
Matamata	3 houses	Surface Flooding	PM 13 April
Te Aroha	1 house (evacuated) 3 commercial buildings	Flooding	AM 14 April

6.1.1 Ex-Tropical Cyclone Debbie (4-6 April)

The community of Waharau Bridge (to the north of Kaiaua, approximately 50-60 people) was isolated due to floodwaters eroding bridge abutments and slips on the northern side of the settlement.

In the Waikato District, 17 district roads were impacted by slips including the road into Port Waikato where 150 school children from Morrinsville were isolated (but safe) due to the road closure.

Some mixing of waste water into stormwater was reported in Ngaruawahia.

Due to actual wind speeds remaining significantly lower than forecast, widespread and persistent power outages were not experienced. However, a telecommunications outage (Spark 3G) was reported at Kaiaua and thought to be associated with the severe weather.

Sewer issues were reported in Morrinsville due to heavy rainfall during Ex-Tropical Cyclone Debbie, including one section where wastewater was flooding across a road and mixing with stormwater. Gully traps were reported to becoming clogged and causing backflows across the Matamata-Piako District.

The Eastern Bulk Main water pipe is exposed to the Waikato River in Hamilton. Careful management of flow in the Waikato River maintained water levels such that the pipeline was not affected.

6.1.2 Tasman Low (11-13 April) and Ex-Tropical Cyclone Cook (13-14 April)

On 13 April at 0500 hours, Thames Coromandel District Council declared a state of emergency in preparation for impacts due to Ex-Tropical Cyclone Cook, particularly possible storm surge around high tide. Thames Valley Emergency Operations Area Civil Defence coordinated a door-knocking campaign to request voluntary evacuation of low-lying areas identified using a combination of coastal setback lines, tsunami modelling and the coastal inundation tool. The impacts were not as severe as predicted and residents were able to return to their houses the following day.

State Highway 2 was closed through the Karangahake Gorge for a short time on 12 April due to flooding.

There were fears that stoplogs would need to be deployed at Criterion Bridge in Paeroa to protect the southern extent of the town. Stoplogs are put in place when the Ohinemuri River recorder at Karangahake Gorge reaches RL 16.5 m. On 13 April at 1935 hours the level peaked at RL 16.174 m.

6.2 Coromandel Zone

6.2.1 Rainfall and river level summary

Rainfall accumulations recorded at Castle Rock during Ex-Tropical Cyclone Debbie were similar to those recorded during the March event (Doc #: 10588909), however totals during Ex-Tropical Cyclone Cook were less significant (Table 13). Three times the average March rainfall fell during March 2017, leaving catchments vulnerable to the rainfall events of April (twice the average April rainfall rate; Table 14). Despite this river flow on the small number of telemetered sites remained above a 50% AEP size (Table 15).

Table 13: Maximum rainfall depths in the Coromandel Zone for a range of durations together with ARI and AEP assessed fromthe NIWA HiRDS model.

Location		Ex-Tropical Cyclone Debbie					Tasman Low and Ex-Tropical Cyclone Cook				
		60 min	12 hour	24 hour	48 hour	72 hour	60 min	12 hour	24 hour	48 hour	72 hour
Matawai Hodder East Rd Castle Rock	Rain (mm)	30.5	149.0	194.5	234	235.0	29	103.5	127.9	164.5	168.9
	AEP (%)	>50	20 to 10	50 to 20	50 to 20	50 to 20	>50	>50	>50	>50	>50
	ARI (yrs)	< 2	5 to 10	2 to 5	2 to 5	2 to 5	< 2	< 2	< 2	< 2	< 2
Kauaeranga Pinnacles	Rain (mm)	30.5	149.0	194.5	234	235.0	31.5	95.5	128.5	192.9	196.9
	AEP (%)	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50
	ARI (yrs)	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2

Table 14: Monthly average rainfall in the Coromandel Zone for March and April compared to 2017 levels, with 100-200% in blue, 200-300% in orange, and >300% in red.

Catchment	Location	Start of monitoring	March 2017 rainfall (mm)	March Ave. (mm)	% of ave.	April 2017 rainfall (mm)	April Ave. (mm)	% of ave.
Matawai	Hodder East Rd Castle Rock	Sep-90	525.5	174	302	477	201	238
Kauaeranga	Pinnacles	Mar-91	999	308	324	572	331	172

Table 15: Maximum river flows for Coromandel Zone sites (m^3/s) recorded during the events with ARI andAEP from established flood frequency relationships for each site.

River	Location	Ex-Tropical Cyclone Debbie				Tasman low and Ex-Tropical Cyclone Cook			
		Flow	Date and Time	ARI (Years)	AEP (%)	Flow	Date and Time	ARI (Years)	AEP (%)
Tairua	Broken Hills	129.0	5/04/2017 4:40	<2	**>50**	230.0	13/04/2017 19:05	<2	**>50**
Tapu	Tapu-Coroglen Road	23.9	5/04/2017 2:00	<2	**>50**	37.0	12/04/2017 16:20	<2	**>50**
Waiwawa	Rangihau Road Ford	208.6	5/04/2017 3:30	<2	**>50**	193.4	12/04/2017 17:20	<2	**>50**

6.2.2 Ex-Tropical Cyclone Debbie (4-6 April)

On 5 April, surface flooding was recorded as widespread in the Coromandel Zone. Some road closures were in place due to slips and tidal flooding, and further road closures were expected during the high tide at 02:00 the next day. There were no immediate concerns with the flood schemes in the Coromandel and flooding was occurring at the usual places. Localised flooding was recorded at Whiritoa Township (not from stream). Contractors cleared a forestry slash blockage at Wharekawa. A culvert in Te Weiti Stream was blocked by sediment.

On 6 April, Coromandel moved from response phase into remediation with efforts being concentrated on assessment and repair of damage caused by the flood event, prioritisation of remediation works, and reporting. River levels in the Coromandel Peninsula continued to run high around high tides, with no immediate concerns reported for the flood schemes.

6.2.3 Tasman Low (11-13 April) and Ex-Tropical Cyclone Cook (13-14 April)

On 13 April, a Civil Defence state of emergency was in place for the Thames Coromandel District with swells expected to create 5 m waves along the east coast. Some people were evacuated from low lying areas along the coast. The potential for debris flows in some already saturated catchments was identified, however large events did not occur. Some minor slumping occurred in the Waiomu Stream at Dehars bend and a tree fell into Te Puru Stream. The Te Weiti Stream bridge culvert was blocked and in the lower reaches the surging tide caused infilling. In general the Coromandel schemes functioned well.

6.3 Waihou/Piako Zone

Waihou/Piako flood protection scheme components discussed in the following sections are identified in Figure 12.

6.3.1 Rainfall and river level summary

The maximum rainfall event was 5 to 2% AEP, recorded at Maukoro Landing over a 48 hour period during Ex-Tropical Cyclone Cook. Other rainfall totals across the Zone did not exceed this level (Table 16). These values are misleading when considering potential impacts due to the saturated state of catchments substantially raising vulnerability. This is better represented when considering monthly rainfall totals compared to previous years. Half of the rainfall sites in the Waihou/Piako Zone had more than three times normal March rainfall, and more than double April volumes (Table 17). This cumulative effect accounts for the small magnitude of rainfall during Ex-Tropical Cyclone Cook producing 1% AEP river flows in the Waihou and Waitoa Rivers (Table 18). The affects can also be seen when assessing the river flow over longer time intervals (Table 19).

Table 16: Maximum rainfall intensities in Waihou/Piako Zone for range of durations for each event with ARI and AEP estimated from the NIWA HiRDS model.

Location		Ex-Tropical Cyclone Debbie					Tasman Low and Ex-Tropical Cyclone Cook				
		60 min	12 hour	24 hour	48 hour	72 hour	60 min	12 hour	24 hour	48 hour	72 hour
Kaihere Maunga-kawa	Rain (mm)	11.5	44.0	75	96.9	97.5	15.5	45.9	52.5	55.5	56.0
	AEP (%)	>50	>50	50 to 20	50 to 20	50 to 20	>50	>50	>50	>50	>50
	ARI (yrs)	< 2	< 2	2 to 5	2 to 5	2 to 5	< 2	< 2	< 2	< 2	< 2
Ohinemuri Queens Head	Rain (mm)	13	57	91.9	117	121.0	23	68.5	83.5	147	147.0
	AEP (%)	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50
	ARI (yrs)	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Piako Maukoro Landing Rd	Rain (mm)	14	73.5	108.5	141.9	142.0	15	51	58.9	86.5	87
	AEP (%)	>50	20 to 10	10 to 5	5 to 2	10 to 5	>50	>50	>50	50 to 20	50 to 20
	ARI (yrs)	< 2	5 to 10	10 to 20	20 to 50	10 to 20	< 2	< 2	< 2	2 to 5	2 to 5
Piako Apple tree	Rain (mm)	18	87	109	136	137	19	59	71	98	100
	AEP (%)	>50	10 to 5	10 to 5	10 to 5	20 to 10	>50	50 to 20	50 to 20	50 to 20	50 to 20
	ARI (yrs)	< 2	10 to 20	10 to 20	10 to 20	5 to 10	< 2	2 to 5	2 to 5	2 to 5	2 to 5
Kaimai	Rain (mm)	19.5	69.99996	102	162.5002	164.0	22.5	129.9996	155.5001	248.0002	255
	AEP (%)	>50	>50	>50	>50	>50	>50	20 to 10	50 to 20	20 to 10	20 to 10
	ARI (yrs)	< 2	< 2	< 2	< 2	< 2	< 2	5 to 10	2 to 5	5 to 10	5 to 10
Tami-hana	Rain (mm)	11.5	44.0	79.9	94.5	97.5	8.5	32.5	37.9	39.5	40
	AEP (%)	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50
	ARI (yrs)	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Waihou Te Aroha	Rain (mm)	16	52.5	90	115.5	116.0	34	70.5	76.9	136.5	136
	AEP (%)	>50	>50	>50	50 to 20	>50	50 to 20	50 to 20	>50	50 to 20	50 to 20
	ARI (yrs)	< 2	< 2	< 2	2 to 5	< 2	2 to 5	2 to 5	< 2	2 to 5	2 to 5
Waite-kauri Golden Cross	Rain (mm)	10	53.5	79.00008	110.5	112.5	24.5	111	135.5	230.5	232.9
	AEP (%)	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50
	ARI (yrs)	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2

Table 17: Monthly average rainfall in Waihou/Piako Zone for March and April compared to 2017 levels, with 100-200% in blue, 200-300% in orange; and >300% in red.

Catchment	Location	Start of monitoring	March 2017 rainfall (mm)	March Ave. (mm)	% of ave.	April 2017 rainfall (mm)	April Ave. (mm)	% of ave.
Kaihere	Maunga-kawa	Dec-92	244.5	87	280	259	97	265
Ohine-muri	Queens Head	Nov-89	419.5	122	344	291	148	196
Piako	Maukoro Landing Rd	Oct-87	245	77	317	256	91	281
Piako	Appletree	Mar-11	333	148	225	265	124	214
Rapu-rapu	Kaimai Summit	Nov-92	500	486	103	167	211	79
Tami-hana	Matamata	Feb-98	300	78	382	166	96	173
Waihou	Te Aroha	Jan-86	320	88	365	285	95	299
Waite-kauri	Golden Cross	Oct-90	578.5	208	278	384	242	159

Table 18: Maximum river flows in Waihou/Piako site (m^3/s) recorded during the events expressed as ARI and AEP estimated from established flood frequency relationships for each site.

River	Location	Ex-Tropical Cyclone Debbie				Tasman low and Ex-Tropical Cyclone Cook			
		Flow	Date and Time	ARI (years)	AEP (%)	Flow	Date and Time	ARI (years)	AEP (%)
Kauaeran-ga	Smiths	172.7	5/04/2017 1:15	<2	**>50**	139.9	13/04/2017 18:35	<2	**>50**
Ohine-muri	Karanga-hake	178.2	5/04/2017 4:55	<2	**>50**	504.4	13/04/2017 19:35	2 to 5	**50 to 20**
Ohine-muri	Queens Head Rock	116.9	5/04/2017 4:00	<2	**>50**	194.6	13/04/2017 21:05	2 to 5	**50 to 20**
Oraka	Pinedale	12.3	6/04/2017 8:20	<2	**>50**	21.3	14/04/2017 7:10	5	**20 to 10**
Piako	Kiwitahi	26.1	6/04/2017 2:50	<2	**>50**	89.8	14/04/2017 0:50	20 to 50	**5 to 2**
Piako	Paeroa-Tahuna Road Bridge	171.3	6/04/2017 9:40	10 to 20	**10 to 5**	189.5	14/04/2017 15:55	10 to 20	**10 to 5**
Piako	Maukoro Landing Rd	3.181	8/04/2017 2:45	10 to 20	**10 to 5**	3.326	15/04/2017 12:50	20 to 50	**5 to 2**
Waihou	Okauia	30.2	6/04/2017 7:10	<2	**>50**	329.6	14/04/2017 2:55	100	**1**
Waihou	Te Aroha	142.0	7/04/2017 21:50	<2	**>50**	360.2	14/04/2017 7:35	10 to 20	**10 to 5**
Waihou	Shaftesbury	17.477	6/04/2017 23:15	2 to 5	**50 to 20**	18.659	14/04/2017 4:35	20 to 50	**5 to 2**
Waihou	Tirohia	4.823	8/04/2017 5:15	2	**50**	5.971	14/04/2017 20:25	10 to 20	**10 to 5**
Waitoa	Mellon Road	67.8	7/04/2017 2:50	5 to 10	**20 to 10**	139.3	14/04/2017 6:10	100	**1**
Waitoa	Waharoa Control	38.4	6/04/2017 13:35	10	**10**	54.5	14/04/2017 13:50	50 to 100	**2 to 1**

Table 19: Mean ARI/AEP values for Waihou/Piako Zone river flows over 72 hours, 7, 14, and 28 days (see Appendix 5 for methodology), with dark red showing <1% AEP, red 5 to 1% AEP, orange 10 to 5% AEP, and yellow 20 to 10% AEP.

		72 hours		7 days		14 days		28 days	
River	**Location**	**ARI (yrs)**	**AEP (%)**	**ARI (yrs)**	**AEP (%)**	**ARI (yrs)**	**AEP (%)**	**ARI (yrs)**	**AEP (%)**
Piako	Paeroa-Tahuna Rd	126	**0.8**	91	**1.1**	184	**0.5**	56	**1.8**
Waitoa	Mellon Road	225	**0.4**	71	**1.4**	52	**1.9**	23	**4.3**
Piako	Maukoro Landing (WL only)	98	**1.0**	41	**2.4**	20	**5.0**	21	**4.8**
Ohinemuri	Karangahake	1.6	**62.5**	1.6	**62.5**	1.6	**62.5**	1.6	**62.5**
Waihou	Te Aroha	24	**4.2**	24	**4.2**	27	**3.7**	18	**5.6**

6.3.2 Ex-Tropical Cyclone Debbie (4-6 April)

Initial assessment on the morning of 5 April found that the Mangawhero Road was experiencing flooding but was still passable (Figure 19). In the Piako River system, the Ngarua Central stopbank (approximately 10% AEP design standard) was spilling, allowing water into the emergency ponding area. Works that were completed in Torehape area after the March event were compromised during high tide. The bank between Northern Canals and Haughs Road stopbank was also overtopped (>2% AEP design standard). The Managawhero pump area was receiving water from stopbank overtopping into the emergency ponding areas, as designed to do at an event of >10% AEP frequency. The Mangawhero and Ngarua Streams also experienced significant sediment deposition (gravel). Pauls Wharf floodgate was returning water to land, the sluice gate was then closed to stop this occurring, as is normal to occur during high flow events. Scott's floodgate was also closed (as designed) to prevent leaking.

Figure 19: Flooding near Mangawhero Road (5/4/2017 08:21 hours).

A number of enquiries were received regarding flooding and damage in Kaiaua. Some residents of Waharoa decided to evacuate properties due to undermining of the road.

On 6 April, the Waihou Valley Scheme progressed to remediation but the Piako River system remained in flood response due to significant surface water. In the Piako River system there were jamming issues at Paul Leonard Floodgate which were subsequently resolved within a

couple of hours. The Ngarua Canal Right stopbank overtopped upstream of the spillway causing scouring of the channel, this was patched until morning when repairs were completed. The design level of this stopbank was less than the flows experienced.

A flight was undertaken over the Waihou/Piako Scheme on 6 April to review the situation (Figure 20). The Piako River ponding zones continued to operate as water levels at the Maukoro Landing site on the Piako River continued to rise above the spillway bank height (10-5% AEP design standard). Hauraki District Council pumps that were pumping into the Pouarua Canal were turned off to reduce additional flooding as WRC pumps were operating at full capacity downstream.

Figure 20: Aerial photograph taken of Piako River flooding (6/4/2017; 15:07 hours).

On the morning of 7 April, the Mangawhero pump had an electrical fault. However, at the time the area was spilling into the Emergency Ponding Zone, therefore was not currently pumping water effectively. This was resolved when spilling stopped approximately 48 hours later, effectively meaning that the pump was only ever not operational when it would not have been in use anyway.

On 8 April, further spilling of water in the Tramway Piako emergency ponding zones occurred overnight and into the morning (designed to start to spill during a 10% AEP event). The water level at the Waikaka pumpstation came very close to over topping with only 20 mm freeboard available (10% AEP design standard).

On 9 April, the emergency ponding zones were still operating, with staff continuing with pumpstation and stopbank checks as well as responding to enquiries.

On 10 April, the Waihou River was still in remediation (where the focus is on repair and maintenance to reinstate pre-event functionality), however the Piako River remained in response (where staff are rostered 24 hours a day to repond to issues as needed). The emergency ponding zones were still operating but the overflow rates were reducing with every tide cycle.

6.3.3 Tasman Low (11-13 April) and Ex-Tropical Cyclone Cook (13-14 April)

Between the 11 and 12 April, river levels in the area remained elevated but did not continue to rise. However, as the rainfall continued by the morning of 13 April, the main channel of the upper Kauaeranga River became blocked.

In the Piako River, the Kerepehi No. 2 stopbank and Carters Cutoff stopbank were overtopping and filling the ponding areas (2% AEP design standard). The end of Awaiti Canal Road was closed due to flooding and two tractor pumps were operating to pump water from the Northern Canal into the Awaiti Canal to lower water levels at the Kerepehi and Carters Cutoff stopbanks.

Figure 21: Spillway operating near Maukoro Landing (14/4/2017).

The full effects of the weather system became apparent on 14 April. In the Waihou River system, the river levels in Te Aroha were the highest they have been in the last decade (10 to 5% AEP peak flow), with the Suburban Outlet Right, Rowes East, and Mangaiti South Upstream Right stopbanks located downstream of the town overtopping (10%, 20%, 40% AEP design standard respectively).

In the Piako River system, the maximum river level of 7.28 m was close to the highest water level of 7.36 m recorded on 8 July 1976 at Paeroa – Tahuna Road, and exceeded highest recorded levels at Maukoro Landing since records began in 1981.

A private stopbank west of Central Drain breached and overtopping occurring at the Russell stopbank and Whakahoro canal (5% AEP design standard).

In the Ohinemuri River system, water levels were receding showing a significant amount of erosion.

During 15 April, in the Piako River system river levels remained at the highest recorded since the 1970's. Overtopping of the stopbank on the Whakahoro Canal left stopbank (5% AEP design) extended for 80 m causing North Road to wash out making it impassable. This impact had not been previously modelled, and further work is needed to better understand this risk. This caused the secondary emergency ponding zone to operate, near where the Piako and Waitoa Rivers converge. Overtopping occurred between Maukoro Landing and Waikaka (Figure 21; 10% AEP design standard). Ponding areas were at capacity with the Pitts Road stopbank (approximately 10% AEP design standard) overtopping during the high tide.

Figure 22: Photograph of flooding around Paeroa-Tahuna Road (17/4/2017).

On 16 April, in the Piako River system, WRC staff were pegging water levels at Ngatea as well as monitoring water levels during the high tides for the next few cycles.

The Piako Scheme continued to operate as expected on 17 April, with the northern ponding zones in the area around the Central Drain filling. The Waitoa river level reduced slightly at the southern end of the Kopuatai Peat Dome (Figure 22), which allowed some small areas of ponded water to return to the river, however this is minor compared to what was still overtopping in the mid reaches into the ponding zones. An aerial inspection was also undertaken to assess conditions.

On 18 April, the Waitoa River continued to recede allowing some areas of ponding water to flow back to the river. Spilling that was recorded along the Maukoro line stopped and indications were that more water was returning to the river than was spilling into ponding areas.

On 19 April, all ponding zone spillway banks stopped overtopping. The Waitoa River and Piako River water levels reduced sufficiently to maintain water within their channels.

The Piako River design standard is 2% AEP, with spillway banks staged at 10-5% AEP. In more severe events (such as the April event) floodwater accumulates in emergency ponding zones. This helps to absorb upper catchment peak runoff and lower peak levels through the lower reaches. As discussed above, ponding and overtopping between 14 and 18 April was experienced in multiple areas (Table 20 and Table 21).

Table 20: Emergency ponding zones spilling 14-18 April in the Waihou/Piako Zone.

Scheme ponding area	Stopbank	Design ARI (years)	Design AEP (%)	Comment
Emergency ponding 1	Maukoro Line	10	10	Spilling
	Tramway Line	10	10	Spilling
	Waikaka	10	10	Spilling
	Central Drain	10	10	
	Mangawhero	10	10	Not spilling from the river
Emergency ponding 2	Russell	20	5	Spilling
	Whakahoro Canal Left	20	5	Spilling, North Road damaged

Table 21: Stopbank overtopping due to the April events in the Waihou/Piako Zone. These points are also mapped in Section 1.2.

Stopbank	Area	Comment
Kerepehi No 2	Awaiti South	Overtopping, no telemetry available but assumed to be greater than a 2% AEP (50 year ARI) event
Kerepehi Cutoff	Awaiti South	Overtopping, no telemetry available but assumed to be greater than 2% AEP (50 year ARI) event
Pitts Road	Torehape	Overtopping at high tide

6.4 Lower Waikato Zone

Lower Waikato flood protection/drainage scheme locations discussed in the following sections are identified in Figure 13.

6.4.1 Rainfall and river level summary

As with the Zones previously discussed, the Lower Waikato had more significant rainfall during Ex-Tropical Cyclone Debbie (5 to 3.3% at Wairamarama and Whangamarino over 12 hours; Table 22), but more significant peak river flows during Ex-Tropical Cyclone Cook (up to 5 to 2% AEP at Mangatangi; Table 23). Again, this was due to the cumulative effect of the rainfall events leading to a prolonged period of high river flows and water levels (Table 24). Monitoring sites showed that rainfall increased up to 450% compared to the March average and up to 317% for April (Table 25).

Table 22: Maximum rainfall depths in the Lower Waikato Zone for each event and a range of durations with ARI and AEP estimated from the NIWA HiRDS model

Location		Ex-Tropical Cyclone Debbie					Tasman Low and Ex-Tropical Cyclone Cook				
		60 min	12 hour	24 hour	48 hour	72 hour	60 min	12 hour	24 hour	48 hour	72 hour
Kaawa Wairama-rama	Rain (mm)	30	110.5	133.0	145.5	146.5	13	26.5	31.9	47.5	64.5
	AEP (%)	20 to 10	5 to 3.3	10 to 5	10 to 5	20 to 10	>50	>50	>50	>50	>50
	ARI (yrs)	5 to 10	20 to 30	10 to 20	10 to 20	5 to 10	< 2	< 2	< 2	< 2	< 2
Whanga-marino Control Structure	Rain (mm)	22	106.5	120.5	132.5	133.5	25.5	47.0	49.0	71.0	78.5
	AEP (%)	>50	5 to 3.3	10 to 5	10 to 5	20 to 10	50 to 20	>50	>50	>50	>50
	ARI (yrs)	< 2	20 to 30	10 to 20	10 to 20	5 to 10	2 to 5	< 2	< 2	< 2	< 2

Table 23: Maximum river flows at the Lower Waikato sites (m^3/s) recorded during the events together with ARI and AEP estimated from established flood frequency relationships for each site.

River	Location	Ex-Tropical Cyclone Debbie				Tasman low and Ex-Tropical Cyclone Cook			
		Flow	Date and Time	ARI (Years)	AEP (%)	Flow	Date and Time	ARI (Years)	AEP (%)
Manga-tangi	SH2 Mara-marua	179.4	5/04/2017 6:50	20 to 50	**5 to 2**	58.8	13/04/2017 22:40	<2	**>50**
Mangata-whiri	SH 2 Mangata-whiri	93.3	5/04/2017 6:35	2 to 5	**50 to 20**	34.0	13/04/2017 22:05	<2	**>50**
Manga-wara	Jefferis Farm Bridge	72.1	5/04/2017 4:05	2 to 5	**50 to 20**	62.1	13/04/2017 21:30	2 to 5	**50 to 20**
Mata-huru	Myjers Farm Bridge	66.5	5/04/2017 8:30	5 to 10	**20 to 10**	41.3	14/04/2017 6:15	<2	**>50**
Mata-huru	Waiterimu Road Below Confluence	70.2	5/04/2017 18:35	5 to 10	**20 to 10**	30.2	14/04/2017 4:30	<2	**>50**
Orere	Orere Point Road Bridge	129.8	5/04/2017 1:15	10 to 20	**10 to 5**	41.0	12/04/2017 16:35	<2	**>50**
Waikato	Mercer Bridge	1231	8/04/2017 17:00	10 to 20	**10 to 5**	1214	17/04/2017 15:50	10 to 20	**10 to 5**
Waikato	Ngarua-wahia (Down stream Waipa)	1094	7/04/2017 21:30	10 to 20	**10 to 5**	974.7	14/04/2017 14:00	5 to 10	**20 to 10**
Waikato	Rangiriri Bridge	1157	8/04/2017 1:10	10 to 20	**10 to 5**	1059	14/04/2017 22:55	5 to 10	**20 to 10**

Table 24: Mean ARI/AEP values for Lower Waikato Zone river flows over 72 hours, 7, 14, and 28 days (see Appendix 5 for methodology), with dark red showing <1% AEP, red 5 to 1% AEP, orange 10 to 5% AEP, and yellow 20 to 10% AEP.

		72 hours		7 days		14 days		28 days	
River	Location	ARI (yrs)	AEP (%)	ARI (yrs)	AEP (%)	ARI (yrs)	AEP (%)	ARI (yrs)	AEP (%)
Waikato	Ngaruawahia	11	**9.1**	8.7	**11.5**	15	**6.7**	8.9	**11.2**
Waikato	Control Structure	14	**7.1**	15	**6.7**	21	**4.8**	14	**7.1**

Table 25: Monthly average rainfall in Lower Waikato Zone for March and April compared to 2017 levels, with 100-200% in blue, 200-300% in orange, >300% in red and black is greatest % of monthly average.

Catch-ment	Location	Start of monitoring	March 2017 rainfall (mm)	March Ave. (mm)	% of ave.	April 2017 rainfall (mm)	April Ave. (mm)	% of ave.
Kaawa	Wairama-rama	Jan-07	277.5	86	324	287	119	241
Whanga-marino	Control Structure	Sep-03	364.5	81	450	249	78	317

6.4.2 Ex-Tropical Cyclone Debbie (4-6 April)

On 5 April, in the Aka Aka Otaua catchment the pumps in the Eastern Drain ceased operating in the early hours of the morning due to an electrical fault. This was remedied the same day. South of Port Waikato, the Kaawa Stream stopbanks were overtopped (lack of telemetry means event size in this area is difficult to quantify but likely above design standard of stopbank). The east compartment at Tuakau experienced flooding caused by internal ponding during the 5 April. At Mangatawhiri, all compartments were overloaded with ponding with compartment 1 and 4 spillways operating (as designed). In the Ruawaro/Waikokowai catchment, the Furniss Upstream stopbanks were overtopped (10% AEP design standard). It is thought that here the flow exceeded the design of the stopbank, however due to limted telemetry this cannot be confirmed. Koheroa Road was cut off due to a local slip at the Mercer end. The Mangatangi River was overtopping at SH2 with the Bell Road compartment inundated by internal ponding and backflow from the SH2 area. In the Mangawara Scheme, the spillways at Smiths and Southees operated during the night, drainage levels in the top of the catchment were reported to be falling with subsequent levels in the lower catchment beginning to rise. The Tenfoot drainage area was experiencing serious internal ponding due to the extreme volume of rain on an already saturated catchment (Figure 23).

On April 6, the Whangamarino gate and Lake Waikare gates were closed at approximately 1100. In the Motukaraka catchment, a 2 person crew was assigned to clear weeds and ensure pump continuity throughout the night. The river level was approaching the top of the stopbank (private, design level not recorded) in Compartment 6 of the Mangatawhiri catchment.

On 7 April, all the pumped catchments within Huntly West had ponded water being pumped. In the Mercer West catchment (Morrison Swamp), the internal stopbanks (approximately 10% AEP design standard) were overtopped due to internal water levels exceeding the design standard (Figure 24). At Kimihia, the main river floodgates were closed due to high river levels leading to some internal ponding. An aerial inspection was undertaken, river levels in tributary streams were observed to be dropping with some reduction in ponded water being observed also.

The Waikato River at Rangiriri peaked at 8.403 m at 0200 on 8 April, this is approaching spillway operation at 8.8 m.

Figure 23: Mangawara River at Tenfoot Road (6 April 2017)

Figure 24: Waikato River - Mercer (6/4/2017)

6.4.3 Tasman Low (11-13 April) and Ex-Tropical Cyclone Cook (13-14 April)

On 13 April, the Mangawara River reached annual flood levels (RL20 m) at Jefferis Bridge. The compartment pumps were keeping up with the inflows. Meremere Main pump 2 flapgate was removed and a new sluicegate was fabricated to better assist with management of higher flows. In the Mangawara catchment, the lower Mangawara floodgates closed and water accumulated behind the stopbanks, e.g. the lower reaches of the Tenfoot drain.

On 14 April, WRC staff were out completing stopbank and pump inspections and were particularly focused on Locke, Mangatawhiri C6 and Parish Polder stopbanks due to their scheme importance and high water levels. The Waikato River at Rangiriri peaked at 8.178 m at 22:45 hours, this is 0.62 m below the operation of the Rangiriri spillway.

A stopbank at the Sampson property (part of the Mercer West Scheme; approximately 10% AEP design standard) failed on 16 April. WRC staff and contractors went to the site to sandbag the breach (Figure 25), which limited the flooding.

Figure 25: Stopbank failure (Sampson property) (14 April 2017).

On 18 April, the Lower Waikato deactivated from response phase (where staff are rostered 24 hours a day to repond to issues as needed) and moved into recovery (where the focus is on repair and maintencance to reinstate pre-event functionality). Mobile tractor pumps continued to assist with ponded water at Bell Road. Pumps at Parish Polder, Mangatawhiri, Churchill East, Motukaraka, Jarland, Johnson, Kitcheners and Higgins were at operating at capacity. No drainage issues were reported.

6.5 Central Waikato and Waipa Zones

6.5.1 Rainfall and river level summary

Whilst the magnitude of rainfall for the Central and Waipa Zones (maximum of 20 to 20% AEP over 12 and 24 hours, and twice April average; Table 26 and Table 27) was less than other neighbouring Zones, peak river levels of 10 to 5% AEP were still recorded (Table 28). These were monitored closely due to the impact on Lower Waikato River levels. Longer time periods did not show flows of greater magnitude (Table 29).

Table 26: Maximum rainfall intensities in Waipa/Central Zones for each event and a range of durations expressed as ARI and AEP based on the NIWA HiRDS model.

Location		Ex-Tropical Cyclone Debbie					Tasman Low and Ex-Tropical Cyclone Cook				
		60 min	12 hour	24 hour	48 hour	72 hour	60 min	12 hour	24 hour	48 hour	72 hour
Waipa Otewa	Rain (mm)	13.5	74.0	101.5	119.0	122.0	23	59.0	61.5	117	128
	AEP (%)	>50	50 to 20	50 to 20	50 to 20	50 to 20	>50	>50	>50	50 to 20	50 to 20
	ARI (yrs)	< 2	2 to 5	2 to 5	2 to 5	2 to 5	< 2	< 2	< 2	2 to 5	2 to 5
Waite-tuna Karamu Walkway	Rain (mm)	17.5	84.9	114	125.5	127.5	9	33	36	68.5	75.5
	AEP (%)	>50	20 to 10	20 to 10	50 to 20	50 to 20	>50	>50	>50	>50	>50
	ARI (yrs)	< 2	5 to 10	5 to 10	2 to 5	2 to 5	< 2	< 2	< 2	< 2	< 2

Table 27: Monthly average rainfall in Waipa/Central Zones for March and April compared to 2017 levels, with 100-200% in blue, 200-300% in orange, >300% in red and black is greatest % of monthly average.

Catchment	Location	Start of monitoring	March 2017 rainfall (mm)	March Ave. (mm)	% of ave.	April 2017 rainfall (mm)	April Ave. (mm)	% of ave.
Waipa	Otewa	May-81	191	95	200	299	109	274

Table 28: Maximum river flows for Waipa/Central sites (m^3/s) recorded during the events expressed as ARI and AEP using established flood frequency relationships for each site.

River	Location	Ex-Tropical Cyclone Debbie				Tasman low and Ex-Tropical Cyclone Cook			
		Flow	Date and Time	ARI (Years)	AEP (%)	Flow	Date and Time	ARI (Years)	AEP (%)
Mangaonua	Dreadnought Culvert SH1	36.7	5/04/2017 16:40	2 to 5	**50 to 20**	36.7	14/04/2017 6:50	2 to 5	**50 to 20**
Waikato	Hamilton Traffic Bridge	669.7	6/04/2017 3:10	10 to 20	**10 to 5**	678.7	14/04/2017 9:30	10 to 20	**10 to 5**
Waipa	Otewa	142.7	5/04/2017 13:55	<2	**>50**	135.7	14/04/2017 7:35	<2	**>50**
Waipa	Pukehoua Bridge	451.2	6/04/2017 23:40	2 to 5	**50 to 20**	374.5	15/04/2017 23:00	2 to 5	**50 to 20**
Waipa	SH23 Bridge Whatawhata	598.0	7/04/2017 16:25	5 to 10	**20 to 10**	470.6	16/04/2017 22:25	2 to 5	**50 to 20**
Waipa	SH31 Bridge Otorohanga	220.5	6/04/2017 3:50	2 to 5	**50 to 20**	177.9	14/04/2017 14:00	<2	**>50**

Table 29: Mean ARI/AEP values for Central Waikato/Waipa Zone river flows over 72 hours, 7, 14, and 28 days (see Appendix 5 for methodology), with dark red showing <1% AEP, red 5 to 1% AEP, orange 10 to 5% AEP, and yellow 20 to 10% AEP.

		72 hours		7 days		14 days		28 days	
River	Location	ARI (yrs)	AEP (%)	ARI (yrs)	AEP (%)	ARI (yrs)	AEP (%)	ARI (yrs)	AEP (%)
Waipa	Otorohanga	1.9	**52.6**	1.6	**62.5**	2.2	**45.5**	1.7	**58.8**
Waipa	Whatawhata	4.9	**20.4**	3.3	**30.3**	5.1	**19.6**	3.3	**30.3**
Waikato	Hamilton	11	**9.1**	9.8	**10.2**	16	**6.3**	9.9	**10.1**

6.5.2 Ex-Tropical Cyclone Debbie (4-6 April)

On 5 April, the Central Zone staff were on standby for flood response and support to other Zones. There were no concerns in the Central Zone. This status was maintained throughout both events.

The Hamilton City Council opened an Emergency Operations Centre to deal with infrastructure issues related to the Main Bulk Water Main that was exposed to the fluctuating river levels.

In the Waipa Zone on 5 April, almost all of the monitored rivers were rising with the three pumpstations in the Otorohanga running during the night to prevent ponding in the town. No flooding issues were reported. Localised flooding was recorded in the Turitea Stream and Maokuraura Stream. The smaller catchments peaked by the afternoon. The Ohote Drain stopbank (20% AEP design standard) was overtopped with several rural roads in the Otorohanga District closed due to flooding.

6.5.3 Tasman Low (11-13 April) and Ex-Tropical Cyclone Cook (13-14 April)

The Waipa River recorded a peak of 470.6 m^3/s at Whatawhata during Ex-Tropical Cyclone Cook. This was lower than the flows recorded during the previous event (598.0 m^3/s). As with Ex-Tropical Cyclone Debbie, localised flooding from small streams and substantial rural ponding occurred. However, no major issues were reported.

6.6 Taupō and Upper Waikato Zones

6.6.1 Rainfall and river level summary

Heavy rainfall at Otaipuhi Station reached 2 to 1 % AEP in magnitude over 48 hours, this placed further pressure on Taupō lake levels and tributaries (Table 30 and Table 31). Rainfall for March and April was almost triple average monthly levels on the western side of Lake Taupō (Table 32).

Table 30: Maximum rainfall intensities in Taupō/Upper Waikato Zones for each event and a range of durations expressed as ARI and AEP using the NIWA HiRDS model.

Location		Ex-Tropical Cyclone Debbie					Tasman Low and Ex-Tropical Cyclone Cook				
		60 min	12 hour	24 hour	48 hour	72 hour	60 min	12 hour	24 hour	48 hour	72 hour
Otupoto Otaipuhi Climate Station	Rain (mm)	15.5	93.5	145.9	186	188.0	16	60.9	69	116.0	123.9
	AEP (%)	>50	10 to 5	2.5 to 2	2 to 1	5 to 3.3	>50	50 to 20	>50	50 to 20	50 to 20
	ARI (yrs)	< 2	10 to 20	40 to 50	50 to 100	20 to 30	< 2	2 to 5	< 2	2 to 5	2 to 5

Table 31: Maximum river flows for Taupō/Upper Waikato sites (m^3/s) recorded during the eventsexpressed as ARI and AEP using established flood frequency relationships for each site.

River	Location	Ex-Tropical Cyclone Debbie				Tasman low and Ex-Tropical Cyclone Cook			
		Flow	Date and Time	ARI (Years)	AEP (%)	Flow	Date and Time	ARI (Years)	AEP (%)
Tauranga-Taupō	Te Kono	207.1	6/04/2017 3:50	5 to 10	**20 to 10**	75.9	14/04/2017 8:15	<2	**>50**

Table 32: Monthly average rainfall in Taupō/Upper Waikato Zones for March and April compared to 2017 levels, with 100-200% in blue, 200-300% in orange, >300% in red and black is greatest % of monthly average.

Catchment	Location	Start of monitoring	March 2017 rainfall (mm)	March Ave. (mm)	% of average	April 2017 rainfall (mm)	April Ave. (mm)	% of average
Outpoto	Otaipuhi Climate Station	Oct-04	276.5	93	297	370	130	284

6.6.2 Ex-Tropical Cyclone Debbie (4-6 April), Tasman Low (11-13 April) and Ex-Tropical Cyclone Cook (13-14 April)

The main concern for the Taupō Zone across all events was the potential for the lake level causing inundation and erosion to lakeside properties. The management of the lake level is discussed in Section 5 (High Flow Management Plan) On 13 April, sand bags were used to provide protection from the rising lake water level to 15 properties at Kuratau. Prior to Ex-Tropical Cyclone Cook modelled forecasts showed that the MCL (Maximum Control Level of RL 357.25 m) would be exceeded. However, lake levels only reached RL 357.243 m.

Significant ponding and localised issues with drainage due to both events occurred in some rural areas around Reporoa.

6.7 West Coast Zone

6.7.1 Rainfall and river level summary

The highest rainfall event recorded during April in the West Coast Zone was a 5 to 3% AEP magnitude over 12 hours at Awaroa, during Ex-Tropical Cyclone Debbie (Table 33). The peak river level in the Zone was also during Ex-Tropical Cyclone Debbie (5 to 2% AEP peak flow recorded at Aranui Caves Bridge; Table 34). This illustrates the faster response times of river levels to heavy rain in the West Coast catchments (compared to the Lower Waikato and Waihou/Piako), as the peak rainfall and river levels occurred during the same time period. This also accounts for the relatively low magnitude calculated when assessing over longer time scales (Table 35). Rainfall totals were over double the April average across the Zone (Table 36).

Table 33: Maximum rainfall intensities in the West Coast Zone for each event and a range of durations expressed as ARI and AEP based on the NIWA HiRDS model.

		Ex-Tropical Cyclone Debbie					Tasman Low and Ex-Tropical Cyclone Cook				
		60 min	12 hour	24 hour	48 hour	72 hour	60 min	2 hour	24 hour	48 hour	72 hour
Awaroa Hauturu Trig	Rain	29	129	167.5	181.5	185.5	16	25	57.5	95.5	119.5
	AEP (%)	50 to 20	5 to 3.3	10 to 5	20 to 10	50 to 20	>50	>50	>50	>50	>50
	ARI (yrs)	2 to 5	20 to 30	10 to 20	5 to 10	2 to 5	< 2	< 2	< 2	< 2	< 2
Mangao-kewa Te Kuiti EWS	Rain (mm)	15	83.5	116.5	126.5	128.5	15.5	19.5	44.5	72.5	87.5
	AEP (%)	>50	20 to 10	10 to 5	20 to 10	50 to 20	>50	>50	>50	>50	>50
	ARI (yrs)	< 2	5 to 10	10 to 20	5 to 10	2 to 5	< 2	< 2	< 2	< 2	< 2
Mangao-kewa Whare-kiri	Rain (mm)	10	64.5	94.0	110.0	112.0	15	27	65.5	105.9	117
	AEP (%)	>50	50 to 20	50 to 20	>50	>50	>50	>50	>50	>50	>50
	ARI (yrs)	< 2	2 to 5	2 to 5	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Mangao-taki Waitan-guru	Rain (mm)	29	99.9	178.0	201	211.5	9.5	13.5	45.5	79.5	92
	AEP (%)	50 to 20	50 to 20	10 to 5	20 to 10	20 to 10	>50	>50	>50	>50	>50
	ARI (yrs)	2 to 5	2 to 5	10 to 20	5 to 10	5 to 10	< 2	< 2	< 2	< 2	< 2
Puniu Bartons Corner Rd Br	Rain (mm)	16	77	120	134	136	28	42	63	98	107
	AEP (%)	>50	20 to 10	10 to 5	20 to 10	50 to 20	50 to 20	20 to 10	>50	50 to 20	>50
	ARI (yrs)	< 2	5 to 10	10 to 20	5 to 10	2 to 5	2 to 5	5 to 10	< 2	2 to 5	< 2
Puniu Ngaroma	Rain (mm)	15	68	96	128	133	13	20	77	137	163
	AEP (%)	>50	>50	>50	>50	>50	>50	>50	>50	>50	50 to 20
	ARI (yrs)	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	2 to 5

Table 34: Maximum river flows for West Coast sites (m^3/s) recorded during the events expressed as ARI and AEP based on established flood frequency relationships for each site.

River	Loca-tion	Ex-Tropical Cyclone Debbie				Tasman low and Ex-Tropical Cyclone Cook			
		Flow	Date and Time	ARI (Years)	AEP (%)	Flow	Date and Time	ARI (Years)	AEP (%)
Awakino	Rauroa Farm Bridge	247.2	5/04/2017 0:05	5 to 10	**20 to 10**	56.8	17/04/2017 10:50	<2	**>50**
Mangao-kewa	Te Kuiti Pump Station	76.6	5/04/2017 14:05	2 to 5	**50 to 20**	53.3	14/04/2017 4:10	<2	**>50**
Puniu	Bartons Corner Road Bridge	195.1	6/04/2017 5:30	5 to 10	**20 to 10**	171.9	14/04/2017 19:45	2 to 5	**50 to 20**
Waitomo	Aranui Caves Bridge	61.5	5/04/2017 8:50	20 to 50	**5 to 2**	9.0	15/04/2017 11:50	<2	**>50**
Oparau	Langdon Road (Off Okupata Road)	76.1	5/04/2017 7:55	2 to 5	**50 to 20**	29.7	15/04/2017 7:30	<2	**>50**

Table 35: Flood frequency analysis for April 2017 (minimum ARI with 95% confidence), with red showing <1% AEP, dark orange 1-2% AEP, and orange >2-5% AEP for West Coast Zone.

		72 hours		7 days		14 days		28 days	
River	Location	ARI (yrs)	AEP (%)	ARI (yrs)	AEP (%)	ARI (yrs)	AEP (%)	ARI (yrs)	AEP (%)
Mangaokewa	Te Kuiti	2.6	**38.5**	2.3	**43.5**	3.2	**31.3**	2.2	**45.5**

Table 36: Monthly average rainfall in the West Coast Zone for March and April compared to 2017 levels, with 100-200% in blue, 200-300% in orange, >300% in red and black is greatest % of monthly average.

Catchment	Location	Start of monitoring	March 2017 rainfall (mm)	March Ave. (mm)	% of ave.	April 2017 rainfall (mm)	April Ave. (mm)	% of ave.
Awaroa	Hauturu Trig	Mar-07	120	111	108	372	208	179
Mangao-kewa	Te Kuiti EWS	Sep-83	154.5	78	198	271	100	271
Mangao-kewa	Wharekiri	Jun-89	180	96	187	282	126	223
Mangao-taki	Waitan-guru	Jun-89	158.5	134	119	410	181	226
Puniu	Bartons Corner Rd Br	Apr-03	219	61	357	276	103	267
Puniu	Ngaroma	Jun-82	231	137	169	380	155	244
Waitetuna	Karamu Walkway	Jan-07	270	97	278	262	126	207

6.7.2 Ex-Tropical Cyclone Debbie (4-6 April)

On 5 April, almost all of the monitored river levels were elevated and rising or steady. Localised ponding was recorded and some roads, including the Awakino Gorge were shut.

7 Debriefings and lessons

Debrief meetings were held at a zone and regional level within WRC. These debriefs focussed on identifying areas where improvements to flood management and response processes could be made. Issues and subsequent recommendations were collected and are currently being prioritised according to need and available resources.

8 Event magnitude summary

Compared to previous years, April 2017 was an exceptionally high rainfall month for the Waikato Region. Impacts were exacerbated by the rapid succession of the three April events, and in some catchments this was worsened by the fact that full recovery after the March rainfall event had not occurred.

Correlating the magnitude of the events and flows to the collective impacts on highly saturated catchments is challenging, as it is difficult to capture cumulative effects in single measurements. Despite this, the magnitude of the event has been considered across a number of telemetered sites for various time periods in order to give an indication of overall maximum magnitude (Table 37).

Table 37: Maximum magnitude river and rainfall levels during April 2017 within each Zone.

Zone		Lower Waikato	Waihou/ Piako	Coromandel	Central	Waipa	West Coast	Taupō/ Upper Waikato
River Level	Max. AEP	4.8	0.4	None greater than annual	6.3	20-10	20-10	20-10
	Time period	14 days	72 hrs		14 days	Peak	Peak	Peak
	Place	Control Structure	Mellon Rd		Hamilton	Whata-whata	Awakino	Tauranga-Taupō
	Flow cumecs	1249.3	WL only		>650	598.0	247.2	207.1
Rain-fall	Max. AEP	5-3	5-3	20-10	20-10	10-5	5-3	2-1.6
	Time pd	12 hr	48 hr	12 hr	24 hr	24 hr	12 hr	24 hr
	Place	Wairama-rama	Maukoro Landing	Castle Rock	Ruakura	Piniu	Hauturu	Otaipuhi Station
	Rain (mm)	110.5	141.9	149.0	91.9	120.0	129.0	186.0

9 References

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Appendix 1: Annual Exceedance Probabilities (AEP) for rainfall

Table 38: Maximum rainfall intensities for each event over various time scales, correlated to magnitude (AEP) using the NIWA HiRDS model.

		Ex-Tropical Cyclone Debbie										Tasman Low and Ex-Tropical Cyclone Cook									
Location		**10 min**	**20 min**	**30 min**	**60 min**	**2 hour**	**6 hour**	**12 hour**	**24 hour**	**48 hour**	**72 hour**	**10 min**	**20 min**	**30 min**	**60 min**	**2 hour**	**6 hour**	**12 hour**	**24 hour**	**48 hour**	**72 hour**
Awaroa Hauturu Trig	**Rain**	8	13	17.5	29	43	72	129	167.5	181.5	185.5	8	10.5	12.5	16	25	36	48.5	57.5	95.5	119.5
	AEP (%)	>50	>50	>50	50 to 20	50 to 20	20 to 10	5 to 3.3	10 to 5	20 to 10	50 to 20	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50
	ARI (yrs)	< 2	< 2	< 2	2 to 5	2 to 5	5 to 10	20 to 30	10 to 20	5 to 10	2 to 5	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Kaawa Wairamarama	**Rain**	7	12.5	17	30	42	61.0	110.5	133.0	145.5	146.5	5.5	7.5	10	13	15.5	23.5	26.5	31.9	47.5	64.5
	AEP (%)	>50	>50	>50	20 to 10	20 to 10	20 to 10	5 to 3.3	10 to 5	10 to 5	20 to 10	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50
	ARI (yrs)	< 2	< 2	< 2	5 to 10	5 to 10	5 to 10	20 to 30	10 to 20	10 to 20	5 to 10	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Kaihere Maungakawa	**Rain (mm)**	3	5	6.5	11.5	15	28.5	44.0	75	96.9	97.5	4	6.5	8.5	15.5	22.5	38.5	45.9	52.5	55.5	56.0
	AEP (%)	>50	>50	>50	>50	>50	>50	>50	50 to 20	50 to 20	50 to 20	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50
	ARI (yrs)	< 2	< 2	< 2	< 2	< 2	< 2	< 2	2 to 5	2 to 5	2 to 5	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Kauaeranga Pinnacles	**Rain (mm)**	10	14.5	18	30.5	48.5	87	149.0	194.5	234	235.0	9	15	19	31.5	40.5	74.5	95.5	128.5	192.9	196.9
	AEP (%)	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50
	ARI (yrs)	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Mangaokewa Te Kuiti EWS	**Rain (mm)**	4.5	7	10	15	23	46.0	83.5	116.5	126.5	128.5	8.5	10.5	11.5	15.5	19.5	33	38.0	44.5	72.5	87.5
	AEP (%)	>50	>50	>50	>50	>50	50 to 20	20 to 10	10 to 5	20 to 10	50 to 20	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50
	ARI (yrs)	< 2	< 2	< 2	< 2	< 2	2 to 5	5 to 10	10 to 20	5 to 10	2 to 5	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
		Ex-Tropical Cyclone Debbie										Tasman Low and Ex-Tropical Cyclone Cook									

Location		10 min	20 min	30 min	60 min	2 hour	6 hour	12 hour	24 hour	48 hour	72 hour	10 min	20 min	30 min	60 min	2 hour	6 hour	12 hour	24 hour	48 hour	72 hour
Mangaokewa Wharekiri	Rain (mm)	3.5	5	6.5	10	18	35.5	64.5	94.0	110.0	112.0	4.5	7.5	9.5	15	27	52.5	60.5	65.5	105.9	117
	AEP (%)	>50	>50	>50	>50	>50	>50	50 to 20	50 to 20	>50	>50	>50	>50	>50	>50	>50	50 to 20	>50	>50	>50	>50
	ARI (yrs)	< 2	< 2	< 2	< 2	< 2	< 2	2 to 5	2 to 5	< 2	< 2	< 2	< 2	< 2	< 2	< 2	2 to 5	< 2	< 2	< 2	< 2
Mangaotaki Waitanguru	Rain (mm)	8.5	13	18	29	41.5	67.5	99.9	178.0	201	211.5	5	6	6	9.5	13.5	22.5	32.0	45.5	79.5	92
	AEP (%)	>50	>50	50 to 20	50 to 20	50 to 20	50 to 20	50 to 20	10 to 5	20 to 10	20 to 10	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50
	ARI (yrs)	< 2	< 2	2 to 5	2 to 5	2 to 5	2 to 5	2 to 5	10 to 20	5 to 10	5 to 10	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Matawai Hodder East Rd Castle Rock	Rain (mm)	10	14.5	18	30.5	48.5	87	149.0	194.5	234	235.0	8.5	16	20	29	37	67.9	103.5	127.9	164.5	168.9
	AEP (%)	>50	>50	>50	>50	50 to 20	50 to 20	20 to 10	50 to 20	50 to 20	50 to 20	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50
	ARI (yrs)	< 2	< 2	< 2	< 2	2 to 5	2 to 5	5 to 10	2 to 5	2 to 5	2 to 5	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Ohinemuri Queens Head	Rain (mm)	6.5	9	10	13	17.5	42	57	91.9	117	121.0	7.5	12.5	16.5	23	31.5	57	68.5	83.5	147	147.0
	AEP (%)	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50
	ARI (yrs)	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Otupoto Otaipuhi Climate Station	Rain (mm)	4.5	6	8.5	15.5	26	52.0	93.5	145.9	186	188.0	5.5	9.5	11.5	16	20.5	46.0	60.9	69	116.0	123.9
	AEP (%)	>50	>50	>50	>50	>50	50 to 20	10 to 5	2.5 to 2	2 to 1	5 to 3.3	>50	>50	>50	>50	>50	50 to 20	50 to 20	>50	50 to 20	50 to 20
	ARI (yrs)	< 2	< 2	< 2	< 2	< 2	2 to 5	10 to 20	40 to 50	50 to 100	20 to 30	< 2	< 2	< 2	< 2	< 2	2 to 5	2 to 5	< 2	2 to 5	2 to 5

		Ex-Tropical Cyclone Debbie	Tasman Low and Ex-Tropical Cyclone Cook

Location		10 min	20 min	30 min	60 min	2 hour	6 hour	12 hour	24 hour	48 hour	72 hour	10 min	20 min	30 min	60 min	2 hour	6 hour	12 hour	24 hour	48 hour	72 hour
Piako Maukoro Landing Rd	Rain (mm)	8.5	11.5	12.5	14	18	48.5	73.5	108.5	141.9	142.0	7	10.5	11	15	25.5	42	51	58.9	86.5	87
	AEP (%)	>50	>50	>50	>50	>50	50 to 20	20 to 10	10 to 5	5 to 2	10 to 5	>50	>50	>50	>50	>50	50 to 20	>50	>50	50 to 20	50 to 20
	ARI (yrs)	< 2	< 2	< 2	< 2	< 2	2 to 5	5 to 10	10 to 20	20 to 50	10 to 20	< 2	< 2	< 2	< 2	< 2	2 to 5	< 2	< 2	2 to 5	2 to 5
Piako Appletree	Rain (mm)	7	10	12	18	22	59	87	109	136	137	5	8	11	19	28	39	59	71	98	100
	AEP (%)	>50	>50	>50	>50	>50	20 to 10	10 to 5	10 to 5	10 to 5	20 to 10	>50	>50	>50	>50	>50	>50	50 to 20	50 to 20	50 to 20	50 to 20
	ARI (yrs)	< 2	< 2	< 2	< 2	< 2	5 to 10	10 to 20	10 to 20	10 to 20	5 to 10	< 2	< 2	< 2	< 2	< 2	< 2	2 to 5	2 to 5	2 to 5	2 to 5
Puniu Bartons Corner Rd Br	Rain (mm)	5	7	9	16	24	47	77	120	134	136	7	13	17	28	42	57	62	63	98	107
	AEP (%)	>50	>50	>50	>50	>50	50 to 20	20 to 10	10 to 5	20 to 10	50 to 20	>50	>50	50 to 20	50 to 20	20 to 10	50 to 20	50 to 20	>50	50 to 20	>50
	ARI (yrs)	< 2	< 2	< 2	< 2	< 2	2 to 5	5 to 10	10 to 20	5 to 10	2 to 5	< 2	< 2	2 to 5	2 to 5	5 to 10	2 to 5	2 to 5	< 2	2 to 5	< 2
Puniu Ngaroma	Rain (mm)	6	10	13	15	18	35	68	96	128	133	5	8	10	13	20	48	67	77	137	163
	AEP (%)	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	50 to 20
	ARI (yrs)	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	2 to 5
Rapurapu Kaimai Summit	Rain (mm)	10.5	12	15.5	19.5	22.5	49.5	69.99996	102	162.5002	164.0	6	11	14.5	22.5	38	83.5002	129.9996	155.5001	248.0002	255
	AEP (%)	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	50 to 20	20 to 10	50 to 20	20 to 10	20 to 10
	ARI (yrs)	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	2 to 5	5 to 10	2 to 5	5 to 10	5 to 10

		Ex-Tropical Cyclone Debbie	Tasman Low and Ex-Tropical Cyclone Cook

Location		10 min	20 min	30 min	60 min	2 hour	6 hour	12 hour	24 hour	48 hour	72 hour	10 min	20 min	30 min	60 min	2 hour	6 hour	12 hour	24 hour	48 hour	72 hour
Tamihana Matamata Aerodrome	Rain (mm)	4	7	8.5	11.5	14.5	31.0	44.0	79.9	94.5	97.5	2	4	5	8.5	13.5	24	32.5	37.9	39.5	40
	AEP (%)	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50
	ARI (yrs)	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Waihou Te Aroha	Rain (mm)	5	7	9	16	20.5	37.0	52.5	90	115.5	116.0	12.5	19.5	23.5	34	45	61.5	70.5	76.9	136.5	136
	AEP (%)	>50	>50	>50	>50	>50	>50	>50	>50	50 to 20	>50	50 to 20	20 to 10	50 to 20	50 to 20	50 to 20	50 to 20	50 to 20	>50	50 to 20	50 to 20
	ARI (yrs)	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	2 to 5	< 2	2 to 5	5 to 10	2 to 5	2 to 5	2 to 5	2 to 5	2 to 5	< 2	2 to 5	2 to 5
Waingaro Ruakiwi Rd Off SH22	Rain (mm)	8	12	16	23	36	48.5	93	105	110.5	112.0	3	5	6.5	8	11	19.5	26.0	27	50.0	66
	AEP (%)	>50	>50	>50	50 to 20	50 to 20	50 to 20	10 to 5	20 to 10	20 to 10	50 to 20	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50
	ARI (yrs)	< 2	< 2	< 2	2 to 5	2 to 5	2 to 5	10 to 20	5 to 10	5 to 10	2 to 5	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Waipa Otewa	Rain (mm)	5	6.5	8	13.5	25	45.5	74.0	101.5	119.0	122.0	8	14	17	23	34	51	59.0	61.5	117	128
	AEP (%)	>50	>50	>50	>50	>50	>50	50 to 20	50 to 20	50 to 20	50 to 20	>50	50 to 20	50 to 20	>50	50 to 20	50 to 20	>50	>50	50 to 20	50 to 20
	ARI (yrs)	< 2	< 2	< 2	< 2	< 2	< 2	2 to 5	2 to 5	2 to 5	2 to 5	< 2	2 to 5	2 to 5	< 2	2 to 5	2 to 5	< 2	< 2	2 to 5	2 to 5
Waitekauri Golden Cross	Rain (mm)	4.5	6	7	10	16.5	38.5	53.5	79.00 008	110.5	112.5	8.5	13	17	24.5	45.5	91.5	111	135.5	230.5	232.9
	AEP (%)	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50
	ARI (yrs)	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2

		Ex-Tropical Cyclone Debbie	Tasman Low and Ex-Tropical Cyclone Cook

Location		10 min	20 min	30 min	60 min	2 hour	6 hour	12 hour	24 hour	48 hour	72 hour	10 min	20 min	30 min	60 min	2 hour	6 hour	12 hour	24 hour	48 hour	72 hour
Waitetuna Karamu Walkway	**Rain (mm)**	5.5	8	11	17.5	28	44.5	84.9	114	125.5	127.5	4	6.5	7.5	9	14	25.5	33	36	68.5	75.5
	AEP (%)	>50	>50	>50	>50	>50	>50	20 to 10	20 to 10	50 to 20	50 to 20	>50	>50	>50	>50	>50	>50	>50	>50	>50	>50
	ARI (yrs)	< 2	< 2	< 2	< 2	< 2	< 2	5 to 10	5 to 10	2 to 5	2 to 5	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Whangamarino Control Structure	**Rain (mm)**	9	13	14.5	22	30.5	77.5	106.5	120.5	132.5	133.5	7	12	16	25.5	33	39	47.0	49.0	71.0	78.5
	AEP (%)	>50	>50	>50	>50	50 to 20	5 to 3.3	5 to 3.3	10 to 5	10 to 5	20 to 10	>50	>50	>50	50 to 20	50 to 20	>50	>50	>50	>50	>50
	ARI (yrs)	< 2	< 2	< 2	< 2	2 to 5	20 to 30	20 to 30	10 to 20	10 to 20	5 to 10	< 2	< 2	< 2	2 to 5	2 to 5	< 2	< 2	< 2	< 2	< 2

A1.1 Rainfall frequency methodology

The initial Rainfall return periods for the events were estimated using a combination of WISKI[1] to extract intensity data and manual comparison with NIWAs HIRDS V3 programme.
WISKI was used to extract the intensity data for durations of 10 minutes through to 72 hours which was then converted to rainfall in mm.

The outputs from HIRDS (https://hirds.niwa.co.nz/) have been loaded to WISKI as reference curves which are used by the WISKI Storm Analysis function to automatically generate return periods from the intensity output. The WISKI window in storm analysis used to extract the rainfall data for March is below Figure 26.

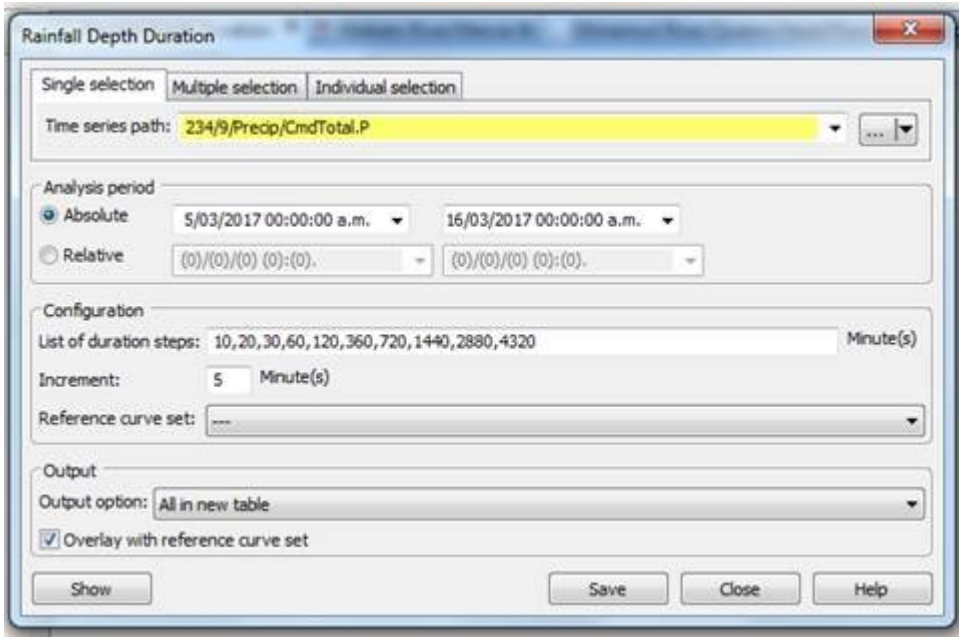


Figure 26: Storm Analysis window in WISKI.

[1] WISKI is environmental data management software used by WRC for managing, analysing and reporting surface water, ground water, water quality, air quality, ecological and meteorological data.

Appendix 2: MetService watches/warnings, and WRC regional hazards advisories

Table 39: MetService warnings (red) and watches (yellow), and WRC regional hazards advisories.

Date/Time	Forecast time	Area	Watch/warning	Forecast	Regional Hazards
3/04/2017 13:59	Monday	Waitomo, Coromandel Peninsula, Rotorua	Severe Weather Watch	Heavy Rain	
3/04/2017 14:00	Monday	Waitomo, Coromandel Peninsula, Rotorua	Weather Watch	Heavy Rain	
3/04/2017 16:18	Monday	Waitomo, Coromandel Peninsula, Rotorua	Weather Watch	Heavy Rain	
3/04/2017 20:37	Monday	Waitomo, Coromandel Peninsula, Rotorua	Severe Weather Watch	Bursts of heavy rain through Wednesday	
4/04/2017 0:30	Tuesday	Thames Coromandel, Waikato	Thunderstorm Warning - Severe	Thunderstorm with heavy rain	
4/04/2017 9:07	Tuesday until 24:00	Coromandel Peninsula, Waikato	Severe Thunderstorm watch	There is a moderate risk that significant convection or slow moving rainbands could bring localised downpours of 25 to 45mm/hr, with or without thunderstorms	
4/04/2017 9:07	Tuesday Morning to 24:00	Waikato, and across to the Coromandel Peninsula.	Severe Thunderstorm Watch	There is a moderate risk that significant convection or low moving rainbands could bring localised downpours of 25 to 45mm/hr, with or without thunderstorms	

Date/Time	Forecast time	Area	Watch/warning	Forecast	Regional Hazards
4/04/2017 9:48	Tuesday	Waikato and Waitomo	Heavy Rain Warning	Heavy rain is expected until Wednesday evening. In the 36 hours, 120-180 of rain may accumulate. Peak intensities 25-45mm per hour and thunderstorms possible.	Regional Hazards Advisory - sent at 10:25, discussing rainfall and weather
4/04/2017 9:48	Tuesday	Coromandel Peninsula	Heavy Rain Warning	Rain is forecast to become heavy this afternoon and to continue until midnight Wednesday. In the 33 hours from 15:00 200 to 300mm may accumulate on the ranges, with lesser amounts 100 to 150mm possible elsewhere. Peak intensities of 25 to 45mm per hour and thunderstorms possible	
4/04/2017 10:15	Tuesday	Taupō, Waikato, Coromandel Peninsula, Waitomo	Severe Weather Watch	Heavy Rain and Strong winds	
4/04/2017 10:15	Tuesday	Taupō, Waikato, Coromandel Peninsula, Waitomo	Severe Weather Watch	Heavy Rain and Strong winds	
4/04/2017 11:46	Tuesday afternoon until late Wednesday	Coromandel Peninsula	Severe weather warning	In the 33 hours from 3pm today until midnight Wednesday, 200 to 300mm may accumulate on the ranges, with lesser amounts of 100 to 150mm possible elsewhere. Peak intensities of 25 to 45mm per hour and thunderstorms possible.	
4/04/2017 21:09	Tuesday evening until 18:00 Wednesday	Waikato - Waitomo and across to the Coromandel Peninsula.	Severe Thunderstorm Watch	There is a continuing risk of localised downpours of 25 to 45mm/hr, with or without thunderstorms	

Date/Time	Forecast time	Area	Watch/warning	Forecast	Regional Hazards Advisory/Update
4/04/2017 21:14	Tuesday	Waikato, Port Waikato	Thunderstorm Warning - Severe	Thunderstorm with heavy rain	
4/04/2017 21:14	Tuesday evening until 22.00 Tuesday	Waikato	Severe Thunderstorm warning	MetService weather radar detected severe thunderstorms. Watch remains in place for Coromandel	
4/04/2017 23:00	Tuesday	Waikato	Thunderstorm Warning	Thunderstorm with heavy rain	
4/04/2017 23:45	Tuesday	Waikato, Coromandel Peninsula	Thunderstorm Warning - Severe , Top priority for immediate broadcast	Thunderstorm with heavy rain	Regional Hazards Advisory - update - sent at 11:59 discussing heavy rain warnings for all the areas in the Waikato Region
5/04/2017 0:00	Wednesday	Coromandel Peninsula - also over other parts of northern NZ, Rotorua and Taupō.	Severe Thunderstorm Watch	Serve thunderstorms and/or downpours through to early hours of Thursday morning (1600). Bringing localised rainfall rates to 25 to 45mm/hr	
5/04/2017 0:00	Wednesday	Thames Coromandel, Waikato	Severe Thunderstorm warning	Weather radar detected severe thunderstorms. Watch in place for Coromandel and Waikato	
5/04/2017 0:00	Wednesday night until 24:00 Thursday	Taupō - with slight risk and/or downpours about parts of Coromandel, Waikato, Waitomo	Severe Thunderstorm watch	Bringing localised rainfall rates of 25 to 40mm/hr	
5/04/2017 1:15	Wednesday	Thames Coromandel, Waikato	Severe Thunderstorm warning	Weather radar detected severe thunderstorms. Watch in place for Coromandel and Waikato	

Date/Time	Forecast time	Area	Watch/warning	Forecast	Regional Hazards Advisory/Update
5/04/2017 1:40	Wednesday morning until 14:30	Taupō, including Coromandel Peninsula	Severe Thunderstorm watch	There is a risk of severe thunderstorms or severe convection during today, bringing a continued risk of localised downpours of 25 to 45mm/hr.	
5/04/2017 3:50	Wednesday afternoon until 06.00am	Taupō, and across Coromandel Peninsula, Rotorua	Severe Thunderstorm Watch	There is a risk of severe thunderstorms or severe convection during today, bringing a continued risk of localised downpours of 25 to 45mm/hr.	
5/04/2017 8:19	Wednesday morning until 09:07am	Thames Coromandel, Waikato	Severe Thunderstorm warning	Weather radar detected severe thunderstorms. Watch in place for Coromandel and Waikato	
5/04/2017 9:07	Wednesday morning to 02:30pm	Coromandel Peninsula and across Taupō.	Severe Thunderstorm watch	A risk of severe thunderstorms or severe convection during today, bringing a continued risk of localised downpours of 25 to 45mmhr	Regional Hazards Advisory sent 17:00, informing of predicted the system moving away.
5/04/2017 9:07	Wednesday until 14:30	Rotorua, and across Comorandel Peninsula and across Taupō	Severe Thunderstorm Watch	There is a risk of severe thunderstorms or severe convection during today, bringing a continued risk of localised downpours of 25 to 45mm/hr.	
5/04/2017 9:07	Wednesday morning to 14:30	Waikato - including Coromandel Peninsula and across Taupō	Severe Thunderstorm watch	There is a risk of severe thunderstorms or severe convection during today, bringing a continued risk of localised downpours of 25 to 45mm/hr.	
5/04/2017 9:07	Wednesday morning until 14.30	Waitomo - including Coromandel Peninsula, Taupō	Severe Thunderstorm watch	There is a risk of severe thunderstorms or severe convection during today, bringing a continued risk of localised downpours of 25 to 45mm/hr	
5/04/2017 9:49	Wedneday through to 06:00am Thursday	Coromandel Penisula and across Taupō	Severe Thunderstorm watch	A risk of severe thunderstorms or severe convection during today, bringing a continued risk of localised downpours of 25 to 45mmhr	
5/04/2017 9:49	Wednesday until 06:00 Thursday	Rotorua, and across Coromandel Peninsula and across Taupō	Severe Thunderstorm Watch	There is a risk of severe thunderstorms or severe convection during today, bringing a continued risk of localised downpours of 25 to 45mm/hr.	

Date/Time	Forecast time	Area	Watch/warning	Forecast	Regional Hazards Advisory/Update
5/04/2017 9:49	Wednesday morning until 06:00 Thursday	Taupō - including Coromandel Peninsula	Severe Thunderstorm Watch	There is a risk of severe thunderstorms or severe convection during today, bringing a continued risk of localised downpours of 25 to 45mm/hr.	
5/04/2017 9:49	Wednesday morning to 06:00am Thursday	Waikato - including Coromandel Peninsula and	Severe Thunderstorm Watch	There is a risk of severe thunderstorms or severe convection during today, brining continued risk of localised downpours of 25 to 45mm/hr.	
5/04/2017 9:49	Wednesday morning until 06.00 Thursday	Waitomo - including Coromandel Peninsula and across Taupō	Severe Thunderstorm watch	There is a risk of severe thunderstorms or severe convection during today, bringing a continued risk of localised downpours of 25 to 45mm/hr	
5/04/2017 10:02	Wednesday	Coromandel Peninsula	Severe weather warning	In the 13 hours from 9am a further 60 to 100mm may accumulate on the ranges, with lesser amounts elsewhere. Peak intensities of 25 to 45mm per hour and thunderstorms are possible	
5/04/2017 15:16	Wednesday afternoon until 24:00	Waikato	Severe Thunderstorm Watch	There is a continuing risk of severe thunderstorms and /or downpours today, brining localised rainfall rates of 25 to 45mm/hr.	
5/04/2017 15:16	Wednesday afternoon to 24:00	Waikato	Severe Thunderstorm Watch	There is a continuing risk of severe thunderstorms and /or downpours today, brining localised rainfall rates of 25 to 45mm/hr.	
5/04/2017 20:26	Wednesday	Coromandel	Severe weather warning	Further bursts of heavy rain are expected until midnight. In the 4 hours from 8pm, a further 20 to 40mm may accumulate on top of what is already fallen. Especially on the ranges. Peak intensities of 15 to 25mm per hour and thunderstorms are possible.	
5/04/2017 20:38	Wednesday evening	Coromandel Peninsula,Waikato, Waitomo and Taupō	Severe Thunderstorm Watch	Severe thunderstorms bringing localised rainfall rates of 25 to 40mm/hr	

Date/Time	Forecast time	Area	Watch/warning	Forecast	Regional Hazards Advisory/Update
5/04/2017 20:38	Wednesday evening until 24:00	Waikato	Severe Thunderstorm watch	There is still a slight risk of severe thunderstorms and/or downpours about parts of Coromandel, Waikato, Waitomo, Taupō through to tonight, brining localised rainfall rates of 25 to	
5/04/2017 20:38	Wednesday Evening until	Waitomo, Waikato, Taupō	Severe Thunderstorm Watch	Bringing localised rainfall rates of 25 to 40mm/hr	
6/04/2017 8:25	Thursday	Waikato, Coromandel Peninsula, Rotorua, Taupō and Waitomo	Severe Weather Warning cancelled		Regional Hazards Advisory - sent 12:00, containing information on river peaks. Regional Flood Response - Update - Sent at 7/4/2017, 17:00 - Update on river systems and informing of e-mail updates.
11/04/2017 9:49	Tuesday	Coromandel Peninsula	Heavy Rain Warning	In the 18 Hours from midday Wednesday 80 to 100mm is forecast to accumulate. Maximum rainfall rates 30 to 40mm per hour with	
11/04/2017 10:20	Tuesday	Waikato, Waitomo	Severe weather watch	A heavy rainfall warning is in forms , large swells an area of damaging severe gales	Regional Hazards Advisory sent at 10:45, which discusses Cyclone Cooks track.
11/04/2017 20:49	Tuesday	Coromandel Peninsula	Severe Weather warning - Heavy rain warning.	Periods of heavy rain are expected. In the 45 hours from 9am Wednesday to 6am Friday, 200 to 250mm is forecast to accumulate. Maximum rainfall rates 30 to 40mm with thunderstorms possible.	
11/04/2017 20:56	Tuesday	Waikato - Taupō, Coromandel Peninsula	Severe Weather warning	A heavy rainfall warning	

Date/Time	Forecast time	Area	Watch/warning	Forecast	Regional Hazards Advisory/Update
11/04/2017 20:56	Tuesday	Waikato, Waitomo	Severe Weather warning	A heavy rainfall warning, large swells an area of damaging severe gales.	
11/04/2017 21:11	Tuesday	Coromandel Peninsula	Severe Weather warning - Heavy rain warning.	Periods of heavy rain are expected. In the 45 hours from 9am Wednesday to 6am Friday, 200 to 250mm is forecast to accumulate. Maximum rainfall	
12/04/2017 10:00	Wednesday until Thursday morning	Coromandel Peninsula and Taupō	Heavy Rain Warning	150 to 250mm is forecast to accumulate. Maximum rainfall rates 30 to 40mm with thunderstorms	
12/04/2017 10:00	Thursday afternoon until Thursday	Coromandel Peninsula	Severe Gales	With gusts of 150km/h or more are possible. Coastal areas in the east can expect large waves of 5 metres	
12/04/2017 10:00	Wednesday through until Thursday night.	Coromandel Peninsula, Taupō	Heavy Rain Warning	In the 39 hours 150 to 250mm is forecast to accumulate. Max rainfall rates 30 to 40mm	
12/04/2017 10:00	Wednesday through to Thursday	Waikato, Waitomo	Severe gales	Severe gales with gusts of 140km/h or more are possible	Regional Hazards Advisory sent at 10:45 discussing Cyclone Cooks track.
12/04/2017 10:48	Wednesday	Taupō, Coromandel Peninsula, Waikato, Waitomo	Heavy Rain Warning	Heavy rain and severe winds of gusts up to 150km/h	
12/04/2017 11:49	Wednesday	Taupō, Coromandel Peninsula, Waikato, Waitomo	Heavy Rain Warning	Heavy rain and severe winds of gusts up to 150km/h	Regional Hazards Advisory sent 18:00 informing of track of Cyclone Cook
12/04/2017 12:43	From Thursday afternoon until Thursday evening	Waikato, Waitomo	Severe gales	Severe gales with gusts of 120km/h or more are possible	
12/04/2017 20:52	Wednesday evening until Thursday evening	Coromandel Peninsula, Rotorua and Taupō	Heavy Rain Warning	In the 24 hours 120 to 160mm is forecast to accumulate, in addition to what has already fallen. Max rainfall rates 30 to 40 m with thunderstorms	

Date/Time	Forecast time	Area	Watch/warning	Forecast	Regional Hazards Advisory/Update
12/04/2017 20:52	From Thursday afternoon until Thursday evening	Coromandel Peninsula	Severe Wind Warning	Severe gales with gusts of 150km/h or more are possible. Also, coastal areas in the east can expect large waves of 5 metres or more.	
12/04/2017 20:52	Until Thursday evening	Waikato, Waitomo	Heavy Rain Warning	In the 24 hours from 8pm Wednesday 100 to 120mm of rain may accumulate. Maximum rainfall rates 25 to 35mm per hour	
12/04/2017 21:11	Wednesday	Waikato, Waitomo, Coromandel Peninsula, Rotorua, Taupō	Severe weather watches	Heavy rain warning, Cyclone is expected to make landfall over the Coromandel peninsula late Thursday afternoon. On track are severe gales of up to 150km/hr	
12/04/2017 21:11	Wednesday	Taupō, Coromandel Peninsula, Waikato, Waitomo	Severe weather watches	Heavy rain is now falling over parts of the country and is expected Thursday or even Friday. On this track are severe gales of up to 150km/h	
13/04/2017 9:14	Thursday late afternoon until evening	Waikato, Waitomo	Severe Wind Warning	Severe gales with gusts of 120km/h or more are possible.	
13/04/2017 9:14	Thursday	Coromandel Peninsula, Rotorua	Heavy Rain Warning	Heavy rain is expected to ease tonight. In the 12 hours from 9am today, 80 to 120mm is forecast to accumulate, in addition to what has already fallen. The heaviest falls are expected from around 3pm, when rainfall rates could reach 25 to 50mm or with thunderstorms possible.	
13/04/2017 9:14	Thursday	Coromandel Peninsula	Severe Wind Warning	From this afternoon until late this evening, severe gales with gusts of 150km/h or more are possible. Also, coastal areas in the east can expect large waves of 5 metres or more during this time, with storm surges near the centre of cyclone, and possible inundation and coastal erosion.	Regional Hazards Advisory sent at 10:30 discussing the effects of Cyclone Cook
13/04/2017 10:09	Thursday	Rotorua, and across Coromandel Peninsula, Taupō, Waikato, Waitomo	Severe weather watches	Heavy Rain and severe gales.	Regional Hazards Advisory sent at 12:00 informing of Cyclone Cook track.

Date/Time	Forecast time	Area	Watch/warning	Forecast	Regional Hazards Advisory/Update
13/04/2017 16:22	Thursday	Coromandel Peninsula,	Heavy Rain Warning	30 to 50mm is forecast to accumulate, in addition to what has already fallen.	
13/04/2017 16:22	Thursday	Coromandel Peninsula	Severe Wind Warning	Severe gales with gusts of 150km/h or more are possible. Expect large waves of 5 metres, storm surges near centre of Cyclone and possible	
13/04/2017 16:22	Thursday	Taupō	Heavy Rain Warning	50 to 70 of rain may accumulate, the heaviest rainfall rates could reach 25 to 35 per hour.	
13/04/2017 16:22	Thursday	Taupō	Severe Wind Warning	Severe gales with gusts of 140km/h or ore are possible.	
13/04/2017 16:22	Thursday	Waikato, Waitomo	Heavy Rain Warning	40 to 60 of rain may accumulate, the heaviest rainfall rates could reach 25 to 35 per hour.	Regional Hazards Advisory sent at 17:00 informing of heavy rain and potential for rivers to rise
13/04/2017 21:04	Thursday	Taupō	Heavy Rain Warning	In the 4 hours from 8pm to midnight 30 to 50mm of rain may accumulate.	
13/04/2017 21:04	Thursday	Waikato, Waitomo	Heavy Rain Warning	In the 4 hours from 8pm to 10pm 20mm of rain may accumulate.	
14/04/2017 12:00	Friday				Regional Hazards Advisory sent at 12:00 hrs discussing favourable forecast, no current alerts for the Waikato Region.

Appendix 3: Annual Exceedance Probabilities (AEP) for instantaneous peak river flows

Table 40: Maximum river flows (m^3/s) recorded during the events converted to magnitude (AEP) using established flood frequency relationships for each site.

River	Location	Ex-Tropical Cyclone Debbie				Tasman low and Ex-Tropical Cyclone Cook			
		Flow	Date and Time	ARI (Years)	AEP (%)	Flow	Date and Time	ARI (Years)	AEP (%)
Awakino	Rauroa Farm Bridge	247.2	5/04/2017 0:05	5 to 10	**20 to 10**	56.8	17/04/2017 10:50	<2	**>50**
Awaroa	Hauturu Road Bridge	**Recorder inactive**							
Kauaeranga	Smiths	172.7	5/04/2017 1:15	<2	**>50**	139.9	13/04/2017 18:35	<2	**>50**
Mangaokewa	Te Kuiti Pumping Station	76.6	5/04/2017 14:05	2 to 5	**50 to 20**	53.3	14/04/2017 4:10	<2	**>50**
Mangaonua	Dreadnought Culvert SH1	36.7	5/04/2017 16:40	2 to 5	**50 to 20**	36.7	14/04/2017 6:50	2 to 5	**50 to 20**
Mangapu	SH3 Br U/S Mangaokewa Confluence	51.4	6/04/2017 14:55	2 to 5	**50 to 20**	26.7	14/04/2017 20:20	<2	**>50**
Mangatangi	SH2 Maramarua	179.4	5/04/2017 6:50	20 to 50	**5 to 2**	58.8	13/04/2017 22:40	<2	**>50**
Mangatawhiri	SH 2 Mangatawhiri	93.3	5/04/2017 6:35	2 to 5	**50 to 20**	34.0	13/04/2017 22:05	<2	**>50**
Mangatutu	Walker Road Bridge	35.1	5/04/2017 17:55	5 to 10	**20 to 10**	35.6	14/04/2017 7:55	5 to 10	**20 to 10**
Mangawara	Jefferis Farm Bridge	72.1	5/04/2017 4:05	2 to 5	**50 to 20**	62.1	13/04/2017 21:30	2 to 5	**50 to 20**
Matahuru	Myjers Farm Bridge	66.5	5/04/2017 8:30	5 to 10	**20 to 10**	41.3	14/04/2017 6:15	<2	**>50**
Matahuru	Waiterimu Road Below Confluence	70.2	5/04/2017 18:35	5 to 10	**20 to 10**	30.2	14/04/2017 4:30	<2	**>50**
Ohinemuri	Karangahake	178.2	5/04/2017 4:55	<2	**>50**	504.4	13/04/2017 19:35	2 to 5	**50 to 20**
Ohinemuri	Queens Head Rock	116.9	5/04/2017 4:00	<2	**>50**	194.6	13/04/2017 21:05	2 to 5	**50 to 20**
Oparau	Langdon Road (Off Okupata Road)	76.1	5/04/2017 7:55	2 to 5	**50 to 20**	29.7	15/04/2017 7:30	<2	**>50**
Opitonui	Dowstream Awaroa Confluence	121.7	4/04/2017 23:45	2	**50 to 20**	56.7	12/04/2017 17:05	<2	**>50**
Oraka	Pinedale	12.3	6/04/2017 8:20	<2	**>50**	21.3	14/04/2017 7:10	5	**20 to 10**
Orere	Orere Point Road Bridge	129.8	5/04/2017 1:15	10 to 20	**10 to 5**	41.0	12/04/2017 16:35	<2	**>50**
Piako	Kiwitahi	26.1	6/04/2017 2:50	<2	**>50**	89.8	14/04/2017 0:50	20 to 50	**5 to 2**
Piako	Paeroa-Tahuna Road Bridge	171.3	6/04/2017 9:40	10 to 20	**10 to 5**	189.5	14/04/2017 15:55	10 to 20	**10 to 5**
Piako	Maukoro Landing Rd	3.181	8/04/2017 2:45	10 to 20	**10 to 5**	3.326	15/04/2017 12:50	20 to 50	**5 to 2**
Puniu	Bartons Corner Road Bridge	195.1	6/04/2017 5:30	5 to 10	**20 to 10**	171.9	14/04/2017 19:45	2 to 5	**50 to 20**
Tairua	Broken Hills	129.0	5/04/2017 4:40	<2	**>50**	230.0	13/04/2017 19:05	<2	**>50**

River	Location	Ex-Tropical Cyclone Debbie				Tasman low and Ex-Tropical Cyclone Cook			
		Flow	Date and Time	ARI (Years)	AEP (%)	Flow	Date and Time	ARI (Years)	AEP (%)
Tapu	Tapu-Coroglen Road	23.9	5/04/2017 2:00	<2	**>50**	37.0	12/04/2017 16:20	<2	**>50**
Tauranga-Taupō	Te Kono	207.1	6/04/2017 3:50	5 to 10	**20 to 10**	75.9	14/04/2017 8:15	<2	**>50**
Waihou	Okauia	30.2	6/04/2017 7:10	<2	**>50**	329.6	14/04/2017 2:55	100	**1**
Waihou	Te Aroha	142.0	7/04/2017 21:50	<2	**>50**	360.2	14/04/2017 7:35	10 to 20	**10 to 5**
Waihou	Shaftesbury	17.477	6/04/2017 23:15	2 to 5	**50 to 20**	18.659	14/04/2017 4:35	20 to 50	**5 to 2**
Waihou	Tirohia	4.823	8/04/2017 5:15	2	**50**	5.971	14/04/2017 20:25	10 to 20	**10 to 5**
Waikato	Hamilton Traffic Bridge	669.7	6/04/2017 3:10	10 to 20	**10 to 5**	678.7	14/04/2017 9:30	10 to 20	**10 to 5**
Waikato	Mercer Bridge	1231	8/04/2017 17:00	10 to 20	**10 to 5**	1214	17/04/2017 15:50	10 to 20	**10 to 5**
Waikato	Ngaruawahia (Downstream Waipa)	1094	7/04/2017 21:30	10 to 20	**10 to 5**	974.7	14/04/2017 14:00	5 to 10	**20 to 10**
Waikato	Rangiriri Bridge	1157	8/04/2017 1:10	10 to 20	**10 to 5**	1059	14/04/2017 22:55	5 to 10	**20 to 10**
Waingaro	Ruakiwi Road Off SH22	100.0	5/04/2017 13:05	10 to 20	**10 to 5**	29.9	14/04/2017 3:05	<2	**>50**
Waipa	Otewa	142.7	5/04/2017 13:55	<2	**>50**	135.7	14/04/2017 7:35	<2	**>50**
Waipa	Pukehoua Bridge on Baffin Road	451.2	6/04/2017 23:40	2 to 5	**50 to 20**	374.5	15/04/2017 23:00	2 to 5	**50 to 20**
Waipa	SH23 Bridge Whatawhata	598.0	7/04/2017 16:25	5 to 10	**20 to 10**	470.6	16/04/2017 22:25	2 to 5	**50 to 20**
Waipa	SH31 Bridge Otorohanga	220.5	6/04/2017 3:50	2 to 5	**50 to 20**	177.9	14/04/2017 14:00	<2	**>50**
Waitoa	Mellon Road	67.8	7/04/2017 2:50	5 to 10	**20 to 10**	139.3	14/04/2017 6:10	100	**1**
Waitoa	Waharoa Control	38.4	6/04/2017 13:35	10	**10**	54.5	14/04/2017 13:50	50 to 100	**2 to 1**
Waitomo	Aranui Caves Bridge	61.5	5/04/2017 8:50	20 to 50	**5 to 2**	9.0	15/04/2017 11:50	<2	**>50**
Waiwawa	Rangihau Road Ford	208.6	5/04/2017 3:30	<2	**>50**	193.4	12/04/2017 17:20	<2	**>50**
Whakapipi	SH22 Bridge	49.2	5/04/2017 3:50	5 to 10	**20 to 10**	13.7	12/04/2017 20:20	<2	**>50**
Wharekawa	Adams Farm Bridge		last download 15/3/17						
Whareroa	Fish Trap	18.4	5/04/2017 19:05	20 to 50	**5 to 2**	14.7	14/04/2017 11:00	10 to 20	**10 to 5**

A3.1 Instantaneous river flow frequency methodology

The return periods for instantaneous flood flow analysis were generated using the internal frequency analysis tool in WISKI.

The Gringorton plotting position and EV1 (Gumbel) distribution were used which is consistent with what has been used in WRC analysis prior to using WISKI analysis.

Return periods beyond maximum extrapolation range are not reported (eg minimum 16 years for 50 year Return Period, 31 years for 100 year). Figure 27 shows the frequency analysis window and sample output from WISKI[2].

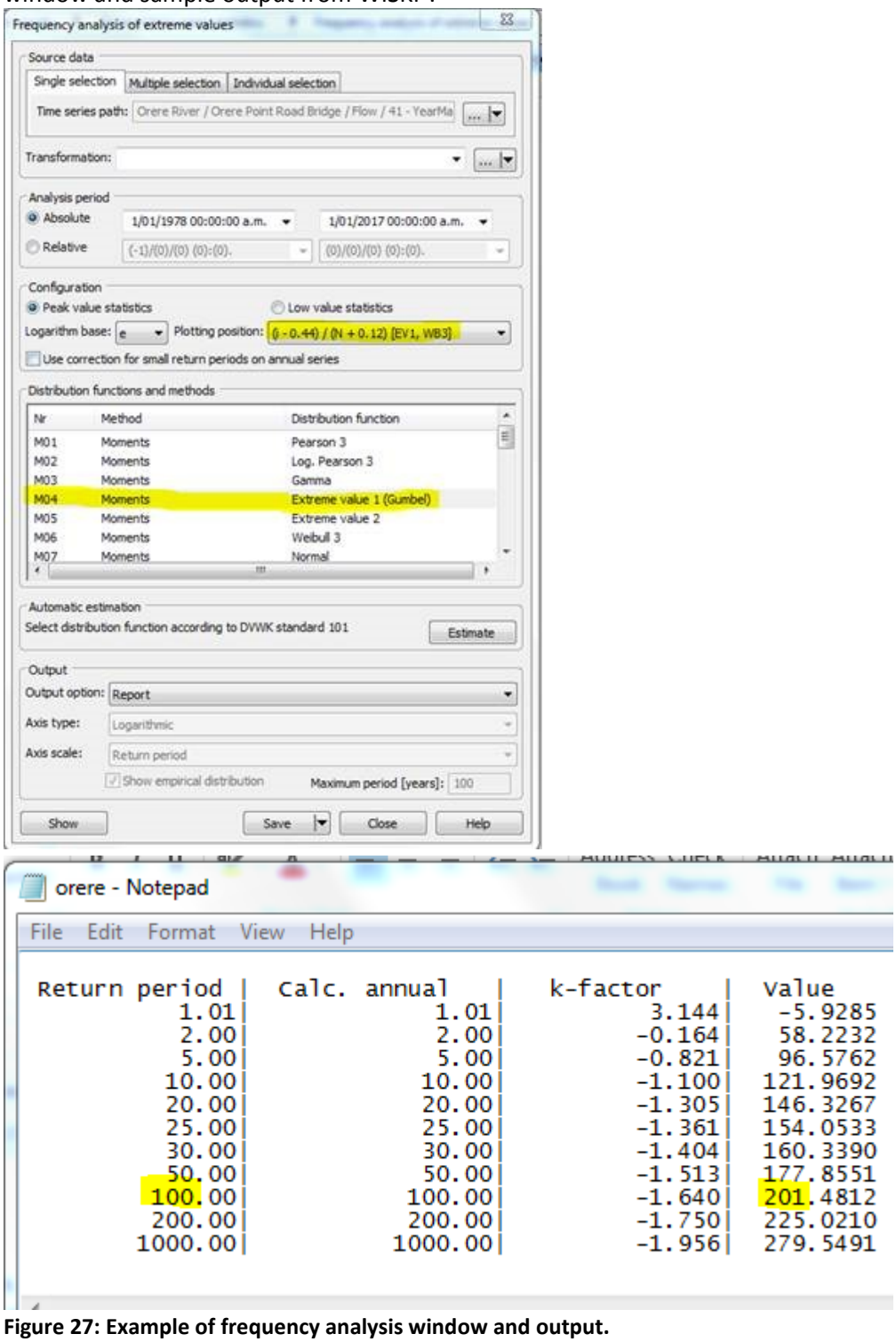


Figure 27: Example of frequency analysis window and output.

[2] WISKI is environmental data management software used by WRC for managing, analysing and reporting surface water, ground water, water quality, air quality, ecological and meteorological data.

Appendix 4: River alarm levels

Table 41: River alarms received through Hydrotel during the April weather events (Blue due to Ex-Tropical Cyclone Debbie, red due to the Tasman Low and/or Ex-Tropical Cyclone Cook.

Time/Date of alarm	River (location)	Level (m RL)	Alarm actions in Regional Flood Response Manual (if applicable)
4/04/2017 11:05:00 a.m.	Awakino (Rauora Farm Bridge)	1.909	
4/04/2017 1:05:00 p.m.		2.525	Possible road closure of SH3.
4/04/2017 4:25:00 p.m.		3.218	SH3 through Awakino Gorge is likely to be inundated.
5/04/2017 6:55:00 p.m.		2.894	
6/04/2017 2:50:00 a.m.		2.199	
7/04/2017 2:20:00 a.m.		1.599	
4/04/2017 3:10:00 p.m.	Waikato (Hamilton)	13.501	
4/04/2017 8:10:00 p.m.		14.003	Grantham Street carpark and sections of river walkways inundated.
5/04/2017 11:40:00 a.m.		15.004	River paths inundated and boat ramps not usable.
8/04/2017 1:55:00 p.m.		14.700	
11/04/2017 4:40:00 a.m.		13.900	
11/04/2017 6:05:00 p.m.		14.000	Grantham Street carpark and sections of river walkways inundated.
12/04/2017 8:30:00 p.m.		15.001	River paths inundated and boat ramps not usable.
19/04/2017 4:30:00 p.m.		14.700	
24/04/2017 7:40:00 a.m.		13.899	
27/04/2017 12:45:00 a.m.		13.396	
27/04/2017 10:30:00 p.m.		13.501	
29/04/2017 4:25:00 a.m.		13.395	
30/04/2017 3:15:00 a.m.		13.502	
30/04/2017 8:25:00 a.m.		13.398	
2/04/2017 5:00:00 p.m.	Waikato (Huntly)	7.500	
4/04/2017 5:40:00 a.m.		7.800	
5/04/2017 4:10:00 p.m.		9.803	
10/04/2017 10:50:00 p.m.		9.500	
13/04/2017 4:55:00 p.m.		9.801	Consult Huntly Flood Management Plan.
21/04/2017 3:40:00 a.m.		9.500	
5/04/2017 2:00:00 a.m.	Ohinemuri (Karangahake)	14.014	Monitor to assist with Paeroa prediction.
6/04/2017 3:35:00 a.m.		13.799	
12/04/2017 6:15:00 p.m.		14.031	Monitor to assist with Paeroa prediction.
13/04/2017 4:55:00 a.m.		13.795	
13/04/2017 4:30:00 p.m.		14.007	Monitor to assist with Paeroa prediction.
13/04/2017 5:55:00 p.m.		15.036	Operations staff on stand-by for stoplog deployment.
13/04/2017 6:25:00 p.m.		15.529	Parts of gorge will begin to flood at 15.8 m.
13/04/2017 7:10:00 p.m.		16.021	30 min readings at Criterion Bridge. Stoplogs to be inserted at 16.5 m.
13/04/2017 8:30:00 p.m.		15.690	
13/04/2017 10:00:00 p.m.		15.188	
14/04/2017 9:55:00 a.m.		13.795	
14/04/2017 12:20:00 a.m.		14.698	

Time/Date of alarm	River (location)	Level (m RL)	Alarm actions in Regional Flood Response Manual (if applicable)
5/04/2017 12:15:00 a.m.	Kauaeranga (Smiths)	7.720	
5/04/2017 12:10:00 p.m.		7.392	
12/04/2017 5:25:00 p.m.		7.730	
12/04/2017 8:20:00 p.m.		7.398	
13/04/2017 10:35:00 p.m.		7.397	
13/04/2017 4:30:00 p.m.		7.701	
5/04/2017 2:05:00 a.m.	Piako (Maukoro Landing)	2.351	
6/04/2017 7:25:00 a.m.		2.754	Monitor Kiwitahi
6/04/2017 5:10:00 p.m.		2.956	
11/04/2017 4:25:00 a.m.		2.700	
12/04/2017 2:25:00 a.m.		2.497	
13/04/2017 11:40:00 p.m.		2.751	
14/04/2017 9:05:00 a.m.		2.951	
15/04/2017 4:40:00 a.m.		3.301	Potentially start sandbagging. Focus to second emergency ponding.
19/04/2017 6:50:00 p.m.		2.997	Readings of gauge boards (Waikaka and Kaihere)
21/04/2017 12:05:00 p.m.		2.699	
22/04/2017 11:25:00 a.m.		2.499	
24/04/2017 2:00:00 a.m.		2.000	
5/04/2017 8:20:00 a.m.	Waitoa (Mellon Road)	7.505	
5/04/2017 8:25:00 p.m.		8.003	North Road levels need to be closely monitored to aid with peak prediction at Maukoro Landing.
6/04/2017 10:40:00 a.m.		8.500	
6/04/2017 12:15:00 a.m.		8.251	
9/04/2017 5:10:00 a.m.		8.249	
10/04/2017 4:45:00 a.m.		8.000	
11/04/2017 1:40:00 p.m.		7.700	
13/04/2017 6:45:00 a.m.		8.001	
13/04/2017 10:50:00 a.m.		8.251	
13/04/2017 5:25:00 p.m.		8.501	
19/04/2017 5:10:00 a.m.		8.250	
20/04/2017 4:40:00 a.m.		7.997	
21/04/2017 3:45:00 p.m.		7.700	
24/04/2017 1:20:00 a.m.		7.197	
4/04/2017 10:25:00 p.m.	Mangatangi (Tower level at Maramarua)	11.048	
4/04/2017 11:50:00 p.m.		12.017	
5/04/2017 2:10:00 a.m.		13.017	
5/04/2017 4:50:00 a.m.		13.514	
5/04/2017 6:05:00 p.m.		13.190	
6/04/2017 8:00:00 a.m.		12.698	
6/04/2017 5:00:00 p.m.		11.686	
7/04/2017 6:25:00 a.m.		10.697	
13/04/2017 4:50:00 p.m.		11.005	
13/04/2017 8:30:00 p.m.		12.008	
14/04/2017 11:30:00 a.m.		11.695	
15/04/2017 1:45:00 a.m.		10.697	

Time/Date of alarm	River (location)	Level (m RL)	Alarm actions in Regional Flood Response Manual (if applicable)
5/04/2017 12:20:00 a.m.	Waikato (Ngaruawahia)	10.501	
5/04/2017 1:00:00 p.m.		11.908	
5/04/2017 12:20:00 a.m.		10.501	
6/04/2017 6:15:00 p.m.		12.600	
8/04/2017 7:50:00 p.m.		12.300	
10/04/2017 6:40:00 a.m.		11.750	
13/04/2017 5:00:00 p.m.		11.901	Discuss flow regimes with Mercury.
20/04/2017 9:00:00 a.m.		11.750	
27/04/2017 2:25:00 a.m.		10.199	
5/04/2017 7:50:00 a.m.	Waipa (Otorohanga)	31.506	
5/04/2017 7:05:00 p.m.		32.702	
6/04/2017 7:25:00 p.m.		32.396	
7/04/2017 10:25:00 p.m.		31.194	
14/04/2017 2:10:00 a.m.		31.510	
16/04/2017 5:20:00 p.m.		31.199	
5/04/2017 1:40:00 a.m.	Piako (P-T Road)	5.517	Check pumpstations and liaise with Land Drainage Manager.
5/04/2017 6:15:00 a.m.		6.007	Ensure monitoring of level recorder at Kiwitahi (Waitoa River).
5/04/2017 6:00:00 p.m.		6.503	
6/04/2017 12:00:00 a.m.		7.003	
7/04/2017 5:20:00 p.m.		6.700	
9/04/2017 12:05:00 a.m.		6.198	
9/04/2017 11:55:00 p.m.		5.200	
9/04/2017 12:45:00 p.m.		5.700	
13/04/2017 3:35:00 a.m.		5.505	
13/04/2017 10:30:00 a.m.		6.006	
13/04/2017 5:45:00 p.m.		6.505	
13/04/2017 11:50:00 p.m.		7.002	
15/04/2017 11:05:00 p.m.		6.699	
17/04/2017 3:45:00 p.m.		6.200	
19/04/2017 3:35:00 a.m.		5.700	
19/04/2017 7:10:00 p.m.		5.200	
6/04/2017 2:45:00 a.m.	Waikato (Rangiriri)	8.000	Request ICM Technical Manager to monitor gate settings.
5/04/2017 11:40:00 a.m.		7.001	
11/04/2017 12:20:00 a.m.		7.700	
14/04/2017 6:00:00 a.m.		8.001	Request ICM Technical Manager to monitor gate settings.
21/04/2017 1:20:00 a.m.		7.700	
25/04/2017 8:55:00 a.m.		6.699	

Time/Date of alarm	River (location)	Level (m RL)	Alarm actions in Regional Flood Response Manual (if applicable)
5/04/2017 8:20:00 a.m.	Tauranga-Taupō	1.504	
5/04/2017 11:10:00 a.m.		1.800	
5/04/2017 3:15:00 p.m.		1.697	
6/04/2017 1:45:00 a.m.		1.807	
6/04/2017 2:40:00 a.m.		2.251	Monitoring of Kiko Road culvert (SH1). Advise NZTA that SHwill be over topped at next alarm (2.5 m). Contact NZ Forestry Managers.
6/04/2017 3:25:00 a.m.		2.508	Possible flooding of Orauanui.
6/04/2017 6:15:00 a.m.		2.198	
6/04/2017 7:45:00 a.m.		1.997	
6/04/2017 11:25:00 p.m.		1.299	
6/04/2017 12:00:00 p.m.		1.696	
2/04/2017 4:35:00 p.m.	Waihou (Te Aroha)	8.999	
3/04/2017 7:00:00 a.m.		8.499	
4/04/2017 9:10:00 p.m.		8.802	
5/04/2017 1:50:00 a.m.		9.302	
5/04/2017 3:55:00 p.m.		9.801	
10/04/2017 8:40:00 a.m.		9.497	
11/04/2017 1:20:00 a.m.		9.000	
11/04/2017 7:50:00 p.m.		8.500	
12/04/2017 4:35:00 p.m.		8.802	
12/04/2017 6:50:00 p.m.		9.307	
13/04/2017 3:35:00 a.m.		9.801	
13/04/2017 8:15:00 p.m.		10.511	
13/04/2017 10:35:00 p.m.		11.001	Constantly monitor river levels for peak. Check Hikutaia Cut Spillway.
14/04/2017 1:05:00 a.m.		11.403	Possible flooding Te Aroha-Paeroa Road (SH26).
15/04/2017 11:05:00 a.m.		11.100	
16/04/2017 11:20:00 a.m.		10.699	
17/04/2017 9:35:00 p.m.		10.199	
20/04/2017 3:25:00 a.m.		9.498	
21/04/2017 9:10:00 a.m.		9.000	
22/04/2017 4:55:00 p.m.		8.499	
5/04/2017 11:35:00 a.m.	Waipa (Whatawhata)	15.508	Possible inundation of Bedford Road.
5/04/2017 9:05:00 p.m.		16.505	Possible inundation of Te Kowhai Road.
7/04/2017 2:20:00 a.m.		18.000	Possible inundation of Karakariki Road. Check Laxton Road Floodgates.
8/04/2017 6:00:00 p.m.		17.694	
10/04/2017 4:05:00 a.m.		16.194	
10/04/2017 7:05:00 p.m.		15.198	
14/04/2017 11:25:00 a.m.		15.503	Possible inundation of Bedford Road.
15/04/2017 11:10:00 a.m.		16.504	Possible inundation of Te Kowhai Road.
19/04/2017 11:00:00 a.m.		16.196	
20/04/2017 1:35:00 p.m.		15.196	

Appendix 5: Methodology memo - Flood frequency analyses for river levels and flows during Ex-Tropical Cyclones Debbie and Cook - April 2017

File No: 30 08 05

Analyses by: Sung Soo Koh

Table 42: List of Sites under investigation

Requested Name	Site Station Key	Site Name	Station Name	Record Length (years)
Te Kuiti	414_13	Mangaokewa Stm	Te Kuiti Pumping Station	34.2
Otorohanga	1191_13	Waipa River	SH31 Br Otorohanga	50.2
Whatawhata	1191_11	Waipa River	SH23 Br Whatawhata	45.1
Hamilton	1131_64	Waikato River	Hamilton Traffic Br	41.4
Ngaruawahia	1131_103	Waikato River	Ngaruawahia Cableway	59.11
Control Structure	1131_165	Waikato River	Whangamarino Control Structure Outlet	36.5
Paeroa-Tahuna Rd Br	749_15	Piako River	Paeroa-Tahuna Rd Br	46.9
Mellon	1249_18	Waitoa River	Mellon Rd Recorder	31
Maukoro (WL only)	749_12	Piako River	Maukoro Landing Rd	65
Karangahake	619_16	Ohinemuri River	Karangahake	60.5
Te Aroha	1122_34	Waihou River	Te Aroha	52.4

The following items information was found for each site:

- Period and number of years record
- The 10,20,50 and 100 year events for each duration analysed
- ARI established for the April 2017 event for each duration of event
- Indication as to whether the April 2017 event was included or excluded from the frequency analysis

A5.1 Method

A5.1.1 Period and number of years record

This information was obtained from gis_all.wiski_ts_timeseries layer using the following queries and merging the resulting tables:

```
select * from gis_all.wiski_ts_timeseries
                where SITE_STATION_KEY in
            ('414_13','1191_13','1191_11','1131_64','1131
```

```
            _103','1131_165','749_15','1249_18','619_16',
            '1122_34')
          and PARAMETERTYPE_SHORTNAME = 'Q'
          and TIMESERIES_SHORTNAME = 'Cmd.P'
```

```
select * from gis_all.wiski_ts_timeseries
          where SITE_STATION_KEY = '749_12'
          and PARAMETERTYPE_SHORTNAME = 'S'
          and TIMESERIES_SHORTNAME = 'Cmd.P'
```

Augmentation of flow records for Mellon and Paeroa-Tahuna Road sites

Along the way of investigation, I was asked to supplement the record history of Mellon and Paeroa-Tahuna Road sites with old record data of Whakahoro (1249_41; 1952-1969). Whakahoro site is located immediately downstream of Mellon site and are spatially close. They all belong to the Piako river. These three sites are expected to have strong hydrological correlations. Scaling based on catchment area was applied using the following equation:

$$Flow_{Mellon} = (CA_{Mellon}/CA_{Whakahoro})^{0.8} \times Flow_{Whakahoro}$$
$$Flow_{P\text{-}T\ Road} = (CA_{P\text{-}T\ Road}/CA_{Whakahoro})^{0.8} \times Flow_{Whakahoro}$$

where CA = Catchment Area

Whakahoro flow recorder site added 18 years records of annual maxima in the extreme flow frequency analysis. Python script was written to extract data from the WRC time-series manager, WISKI, and stored the annual maxima in a csv file, Murray Maxima {site station key}.csv. These files were included in the attachment and the data in these files were used in the subsequent frequency analysis. Table 43 shows an example of what the files look like. They contain peak, 72h, 7d, 14d, 28d event maxima for the years starting on 1 Jan.

Python Code for peak, 72h, 7d, 14d, 28d event maxima extraction + Whakahoro supplement

Step 1. Load the site list which store site station key for accessing WISKI

```
# list of sites
site_list = pd.read_csv('Murray_sites_python.csv')
```

Step 2. Extract Yearly maximum values for each site, process peak maxima

Note the catchment area based scaling of Whakahoro to supplement Mellon and Piako in the middle of script.

```
# Obtain Year.Max Series
peak_TS = []
for i in range(len(site_list)):

api.timeSeries.getData(path='{}/Year.Max'.format(site_list['path'][i])
)
    output = api.timeSeries.data.dropna(axis=0,how='any')['value']
    peak_TS.append(output)
print 'Year.Max Extraction Done'
```

```
# Supplement Historic Maukoro Year.Max series
Maukoro_supplement     =     pd.read_csv('Maukoro_historic_record_1952-
1979.csv')
Maukoro_supplement.dropna(axis=0,how='any',inplace=True)
Maukoro_supplement['timestamp'] = Maukoro_supplement.apply(lambda row:
pd.Timestamp(row['Year'],1,1),axis=1)
Maukoro_supplement.index = Maukoro_supplement['timestamp']
peak_TS[8] = peak_TS[8].append(Maukoro_supplement['Level'])
```

```
print 'Maukoro Supplement Done'

# Supplement Piako PT and Mellon using Whakahoro
api.timeSeries.getData(path='1249/41/Flow/Year.Max')
Whakahoro_CA = api.timeSeries.metadata[u'station_CATCHMENT_SIZE']
api.timeSeries.getData(path='1249/18/Flow/Year.Max')
Mellon_CA = api.timeSeries.metadata[u'station_CATCHMENT_SIZE']
api.timeSeries.getData(path='749/15/Flow/Year.Max')
PiakoPT_CA = api.timeSeries.metadata[u'station_CATCHMENT_SIZE']

Piako_CA_Scaling_Ratio = (PiakoPT_CA/Whakahoro_CA)**0.8
Mellon_CA_Scaling_Ratio = (Mellon_CA/Whakahoro_CA)**0.8
print 'Estimated the Catchment Area ratios for Piako PT and Mellon'

PiakoPT_YearMax_Historic = peak_TS[11] * Piako_CA_Scaling_Ratio
Mellon_YearMax_Historic = peak_TS[11] * Mellon_CA_Scaling_Ratio

peak_TS[6] = peak_TS[6].append(PiakoPT_YearMax_Historic)
peak_TS[7] = peak_TS[7].append(Mellon_YearMax_Historic)
print 'Appended Whakahoro scaled values to Piako PT and Mellon'
print 'ALL DONE'
```

Step 3. Extract 72h, 7d, 14d, 28d data

Transformation argument in the WISKI API call was used to chain transforms on the raw record data. First moving average of appropriate duration period (i.e. 3d,7d,14d,28d) then finding yearly maximum.

```
def Whakahoro_addition(TS_dump):
    PiakoPT_YearMax_Historic = TS_dump[11] * Piako_CA_Scaling_Ratio
    Mellon_YearMax_Historic = TS_dump[11] * Mellon_CA_Scaling_Ratio

    TS_dump[6] = TS_dump[6].append(PiakoPT_YearMax_Historic)
    TS_dump[7] = TS_dump[7].append(Mellon_YearMax_Historic)
    print 'Appended Whakahoro scaled values to Piako PT and Mellon'

# Obtain Cmd.P 3day moving mean Series
import sys
MM3day_TS = []
print '3day moving mean Extraction'
for i in range(len(site_list)):
    sys.stdout.write('.')

api.timeSeries.getData(path='{}/Cmd.P'.format(site_list['path'][i]),tr
ansformation='movavg(3day);maximum(1year)')
    output = api.timeSeries.data.dropna(axis=0,how='any')['value.max']
    MM3day_TS.append(output)
print 'Done'
Whakahoro_addition(MM3day_TS)

# Obtain Cmd.P 7day moving mean Series
import sys
MM7day_TS = []
print '7day moving mean Extraction'
for i in range(len(site_list)):
    sys.stdout.write('.')

api.timeSeries.getData(path='{}/Cmd.P'.format(site_list['path'][i]),tr
ansformation='movavg(7day);maximum(1year)')
    output = api.timeSeries.data.dropna(axis=0,how='any')['value.max']
    MM7day_TS.append(output)
print 'Done'
Whakahoro_addition(MM7day_TS)


# Obtain Cmd.P 14day moving mean Series
```

```
import sys
MM14day_TS = []
print '14day moving mean Extraction'
for i in range(len(site_list)):
    sys.stdout.write('.')

api.timeSeries.getData(path='{}/Cmd.P'.format(site_list['path'][i]),tr
ansformation='movavg(14day);maximum(1year)')
    output = api.timeSeries.data.dropna(axis=0,how='any')['value.max']
    MM14day_TS.append(output)
print 'Done'
Whakahoro_addition(MM14day_TS)

# Obtain Cmd.P 28day moving mean Series
import sys
MM28day_TS = []
print '28day moving mean Extraction'
for i in range(len(site_list)):
    sys.stdout.write('.')

api.timeSeries.getData(path='{}/Cmd.P'.format(site_list['path'][i]),tr
ansformation='movavg(28day);maximum(1year)')
    output = api.timeSeries.data.dropna(axis=0,how='any')['value.max']
    MM28day_TS.append(output)
print 'Done'
Whakahoro_addition(MM28day_TS)

print 'ALL DONE'
```

Step 4. Save the extracted data into files

Extracted data was packaged in a dataframe then saved as csv's.

```
maxima_dump = []
for i in range(len(site_list)):
    df = pd.DataFrame()
    df['Peak'] = peak_TS[i]
    df['3 Day'] = MM3day_TS[i]
    df['7 Day'] = MM7day_TS[i]
    df['14 Day'] = MM14day_TS[i]
    df['28 Day'] = MM28day_TS[i]
    df.to_csv('Murray  maxima  {}.csv'.format(site_list['Site  Station
Key'][i]))
    maxima_dump.append(df)
print 'Done'
```

Table 43:Example of base data table csv. 1131_103 Ngaruawahia Annual Maxima Base Data

timestamp	Peak	3 Day	7 Day	14 Day	28 Day
1/01/1957	579.9282	540.1375	495.1664	448.2574	434.5118
1/01/1958	1542.863	1420.137	1111.934	840.8402	588.9828
1/01/1959	610.9066	580.9764	652.3367	590.6925	531.5173
1/01/1960	941.3575	892.3846	762.5953	595.0673	492.533
1/01/1961	961.3289	928.1825	776.542	581.1003	477.6282
1/01/1962	959.7329	920.424	773.0994	763.4079	677.311
1/01/1963	731.228	689.2864	615.6684	552.8912	533.0339
…	…	…	…	…	…
1/01/2015	769.7441	734.1628	698.2672	594.6788	546.4996
1/01/2016	822.7982	786.4823	741.3352	679.2274	571.0688
1/01/2017	1093.931	1047.052	921.0564	898.5666	730.7736

A5.1.2 Frequency analysis

Frequency analysis of the flood events were performed on the prepared data. This was done by first identifying the most appropriate probability distributions for the dataset. WRC's time-series manager, WISKI has a handy tool that can find the best probability distribution for given extreme value dataset.
The WISKI's frequency analysis tool has the capability of choosing the best probability distribution out of collection of 10 distributions. Section A5.1.2.2 outlines the choice of the best probability distribution for the data obtained in each site in interest. Then, section A5.1.2.3 and A5.1.2.4 describes the method used to create the 10, 20, 50 and 100-year design flow tables.

A5.1.2.1 WISKI frequency analysis tool for extreme values

The suitable tool for this analysis is the WISKI Extreme Value Frequency Analysis Tool which can be found in systems view in WISKI. To open up the System View Window, click the system view icon in the menu strip at the top of the WISKI software (Figure 28).

Then, use the treeview on the left side of the popped up System View window to locate the Frequency analysis of extreme values tool (Figure 29). Right-click and open.

The user interface of the tool (Figure 30) allows the users to enter the desired time-series for analysis, analysis period, whether high-flow or low-flows are analysed, which distribution functions are going to be used to fit the empirical data, and output type (either graphs or table).

Figure 28: Location of System View Icon.

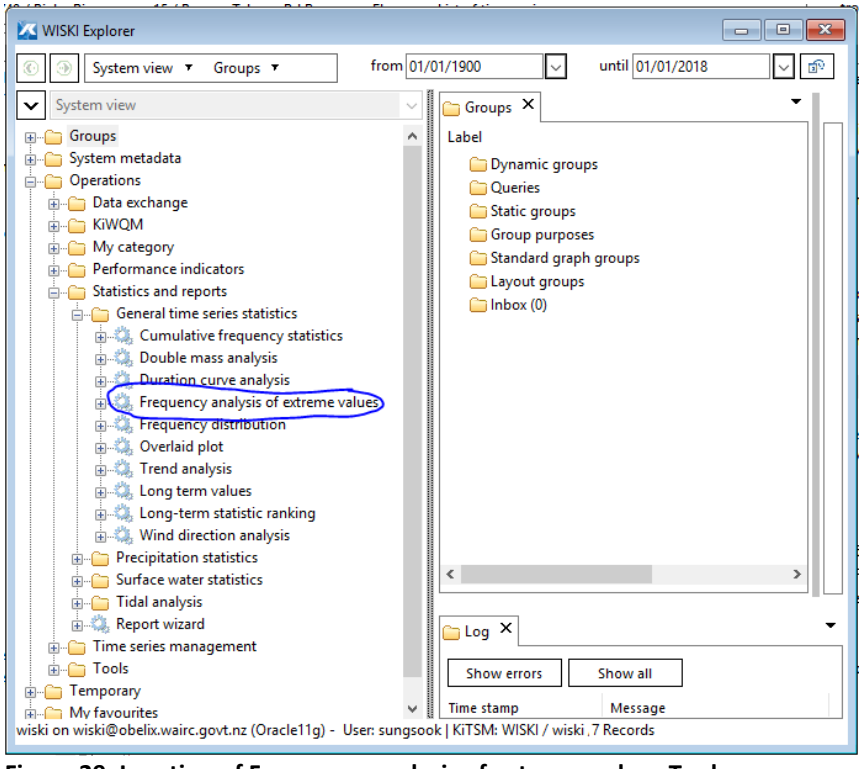


Figure 29: Location of Frequency analysis of extreme values Tool.

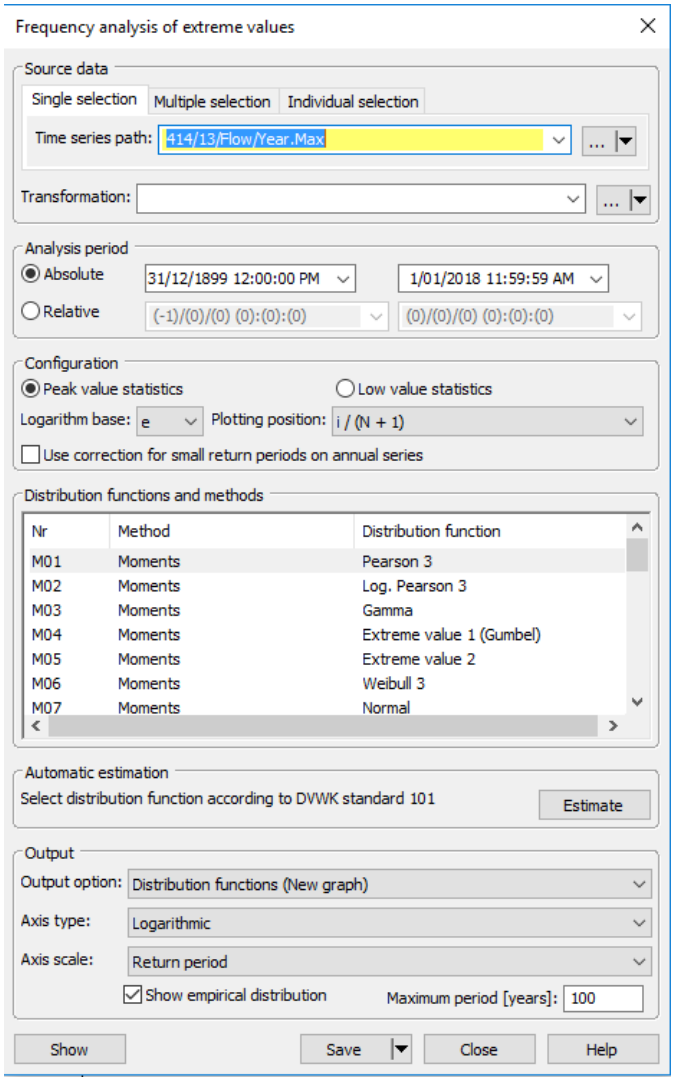


Figure 30: Frequency Analysis Tool User Interface.

A5.1.2.2 Best Distribution Choice

WISKI chooses the best distribution function to fit the empirical yearly maxima according to DVWK standard 101 method (DVWK 1999). The probability and method choice was asked to be consistent over each sites. WISKI software was used to find out which method and probability distribution choice best fitted the maxima for each parameter combination. Then the rule of majority was used to identify the probability distribution that worked best for each site.

In the upper part of the frequency analysis tool User Interface (Figure 31), the time-series path, analysis period and configuration were entered. After the configurations were entered, pushing Estimate button will produce the WISKI's choice based on a fit performance measure, named DVWK standard. This process was repeated per each combination of sites and moving average durations. The results were recorded in Table 44 and the most frequently appearing probability distribution was chosen as the distribution for the site. For example, the Hamilton site had four occurrences of Log Pearson and one occurrence of Gamma. So, the subsequent analysis of Hamilton site used Log Pearson function for distribution fitting.

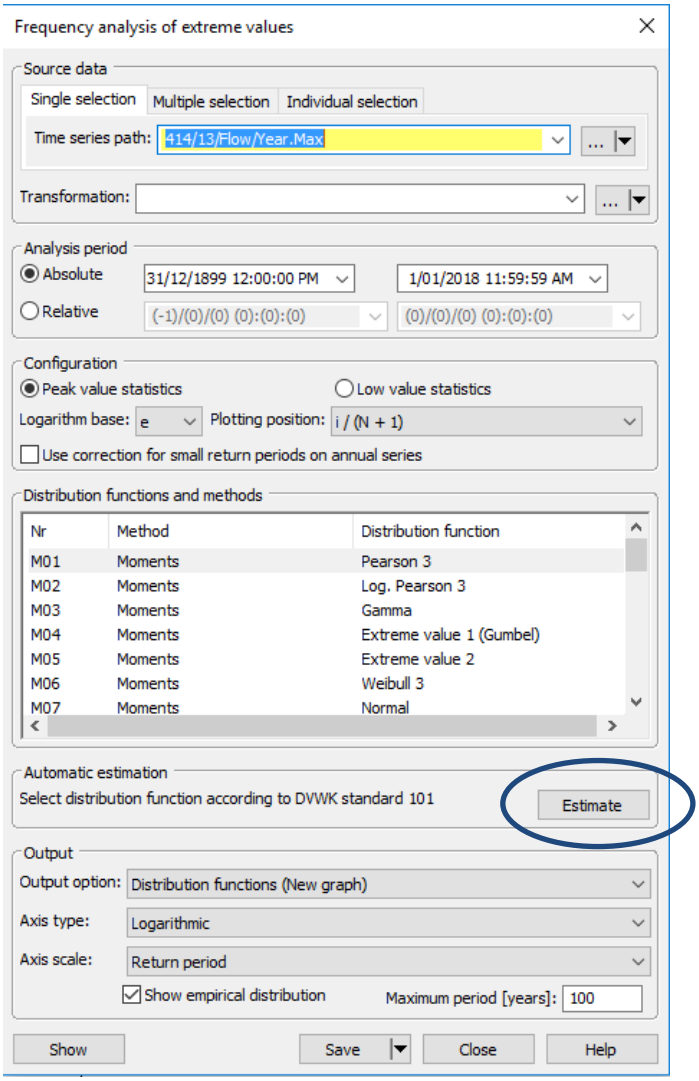


Figure 31: Automatic Estimation Button after selecting the input parameter.

Table 44: Best fitting/probability for design flood fits. Method of fit = Moments, both Pearson and Log Pearson refer to 3 parameter functions. i.e. Pearson 3 and Log Pearson 3 respectively.

Requested Name	Station Key	peak	72h	7d	14d	28d	Choice
Te Kuiti	414_13	Log Pearson	Pearson	Log Pearson	x	x	Log Pearson
Otorohanga	1191_13	Pearson	Gamma	Gamma	x	x	Gamma
Whatawhata	1191_11	Pearson	Gamma	Pearson	Gamma	x	Pearson
Hamilton	1131_64	Log Pearson	Log Pearson	Log Pearson	Log Pearson	Gamma	Log Pearson
Ngaruawahia	1131_103	Log Pearson	Pearson	Pearson	Pearson	Log Pearson	Pearson
Control Structure	1131_165	Gamma	Gamma	Gamma	Gamma	Gamma	Gamma
Paeroa-Tahuna Rd Br	749_15	Log Pearson	Pearson	Gamma	Pearson	x	Pearson
Mellon	1249_18	Log Pearson	Log Pearson	Log Pearson	Log Pearson	x	Log Pearson
Maukoro (WL only)	749_12	Gamma	Gamma	Gamma	Gamma	x	Gamma
Karangahake	619_16	Gamma	Pearson	Log Pearson	Log Pearson	x	Log Pearson

Te Aroha	1122_34	Log Pearson	Log Pearson	Log Pearson	Log Pearson	x	Log Pearson

A5.1.2.3 Return Period Plot and fitted parameters

The annual maxima were sorted and fitted to the cumulative distribution curve using a scipy.optimization function, curve_fit. By default, the curve_fit function minimizes the least square of residuals. Figure below shows what sorted maxima look like and the figure below show the result of the fitted curve. Since Gamma distribution is a special case of Pearson-3 distribution, datasets were fitted to either Pearson-3 or LogPearson-3 distribution to estimate the fitted parameters.

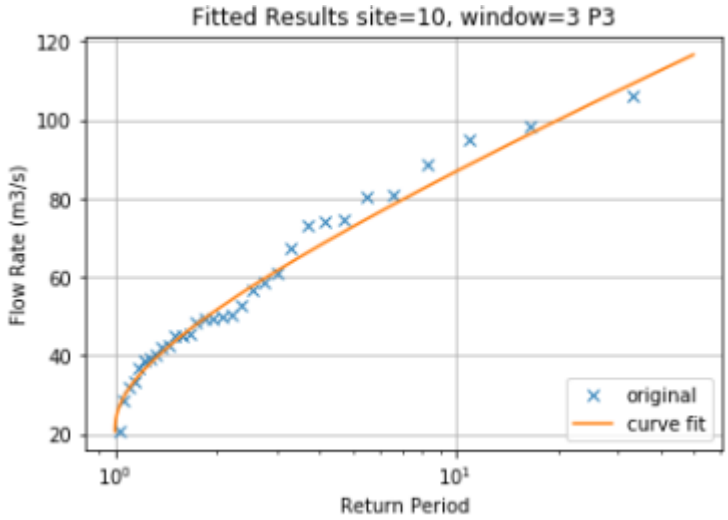


Figure 32: Example of curve_fit result to annual maxima, plotted in semilogx axis. 1122_34 Te Aroha(14d) fitted with Pearson-3 distribution.

Python Script

Step 1. Import necessary modules

```
from scipy.stats import weibull_min
from scipy.stats import pearson3
from scipy.stats import gamma
from scipy.stats import skew
from scipy.optimize import newton
from scipy.optimize import curve_fit
import matplotlib.pyplot as plt
import numpy as np
import pandas as pd
from wiski.rest import API
api = API()
%matplotlib inline
```

Step 2. Curve fit caller functions

`YearMax2DesignLevels` is the main curve fitting function that is used in Step 3.

```
def func_pearson3(x,a,b,c):
    return pearson3.cdf(x, a, loc=b, scale=c)

def func_gamma(x,a,b,c):
    return gamma.cdf(x, a, loc=b, scale=c)

def YearMax2DesignLevels(series,dist='Pearson3',report=False):
    if dist == 'Pearson3-curve_fit':
        if report:
```

```
            print 'Pearson3 Distribution was fitted using minimum
residual curve fit method.'
        xdata = np.linspace(0, 1, len(series)+2)
        xdata = xdata[1:-1]
        series.sort_values(inplace=True)

        p0 = np.array([0.5,series.mean(),series.std()])
        coeffs, matcov = curve_fit(func_pearson3, series, xdata, p0)
        if report:
            print 'skew {}, loc {}, scale
{}'.format(coeffs[0],coeffs[1],coeffs[2])

        curve_x = np.linspace(series.min(),series.max()*1.1,1000)
        ydata = pearson3.cdf(curve_x, coeffs[0], loc=coeffs[1],
scale=coeffs[2])
        if report:
            fig = plt.figure()
            plt.semilogx(1/(1.0-xdata),series,'x')
            plt.semilogx(1/(1.0-ydata),curve_x)
            plt.grid(True)
            plt.legend(['original','curve fit'],loc=4)
            plt.xlabel('Return Period')
            plt.ylabel('Flow Rate (m3/s)')
            plt.title('Fitted Results site={}, window={}
P3'.format(siteID,windowID))
            fig.savefig('Q:/Sungsoo/Murray site {} window {}
P3.png'.format(siteID,windowID))

        return coeffs

    elif dist == 'LogPearson3-curve_fit':
        if report:
            print 'Log.Pearson3 Distribution was fitted using minimum
residual curve fit method.'
        xdata = np.linspace(0, 1, len(series)+2)
        xdata = xdata[1:-1]
        series.sort_values(inplace=True)
        log_series = np.log(series)

        p0 = np.array([0.5,log_series.mean(),log_series.std()])
        coeffs, matcov = curve_fit(func_pearson3, log_series, xdata,
p0)
        if report:
            print 'skew {}, loc {}, scale
{}'.format(coeffs[0],coeffs[1],coeffs[2])

        curve_x = np.linspace(series.min(),series.max()*1.2,1000)
        ydata = pearson3.cdf(np.log(curve_x), coeffs[0],
loc=coeffs[1], scale=coeffs[2])
        if report:
            fig = plt.figure()
            plt.semilogx(1/(1.0-xdata),series,'x')
            plt.semilogx(1/(1.0-ydata),curve_x)
            plt.grid(True)
            plt.legend(['original','curve fit'],loc=4)
            plt.xlabel('Return Period')
            plt.ylabel('Flow Rate (m3/s)')
            plt.title('Fitted Results site={}, window={}
LP3'.format(siteID,windowID))
            fig.savefig('Q:/Sungsoo/Murray site {} window {}
LP3.png'.format(siteID,windowID))

        return coeffs
```

Step 3. Curve fit all 10 sites, 5 different event durations and estimate fit parameters

The estimated parameters are stored in 6 lists named Pearson3_shape ~ LogPearson3_scale. These lists of fitted parameters are used to read off design flows and ARIs and in Monte Carlo simulation of sampling for uncertainty analysis.

```
# list of sites
site_list = pd.read_csv('Murray_sites_python.csv')
maxima_dump2 = []
for i in range(len(site_list)):
    df = pd.read_csv('Murray maxima {}.csv'.format(site_list['Site
Station Key'][i]),index_col=0)
    maxima_dump2.append(df)
print 'Done'


Pearson3_shape = np.zeros((len(site_list)-1,5))
Pearson3_loc = np.zeros((len(site_list)-1,5))
Pearson3_scale = np.zeros((len(site_list)-1,5))
LogPearson3_shape = np.zeros((len(site_list)-1,5))
LogPearson3_loc = np.zeros((len(site_list)-1,5))
LogPearson3_scale = np.zeros((len(site_list)-1,5))

for siteID in range(len(site_list)-1): # site location index
    for windowID in range(5):  # moving average window size index:
0=peak, 4=28day

        x = maxima_dump2[siteID].iloc[:,windowID].copy()
        x.dropna(inplace=True)
        fit_dist = site_list['Distribution'][siteID]
        if 'Gamma' not in site_list['Distribution'][siteID]:
            fit_dist = site_list['Distribution'][siteID]+'-curve_fit'
        else:
            fit_dist = 'Pearson3-curve_fit'

        try:
            temp = YearMax2DesignLevels(x,'Pearson3-curve_fit')
            Pearson3_shape[siteID,windowID] = temp[0]
            Pearson3_loc[siteID,windowID] = temp[1]
            Pearson3_scale[siteID,windowID] = temp[2]
            print '[{},{}] Pearson3 Success'.format(siteID,windowID)
        except:
            print '[{},{}] Pearson3 Failed'.format(siteID,windowID)


        try:
            temp = YearMax2DesignLevels(x,'LogPearson3-curve_fit')
            LogPearson3_shape[siteID,windowID] = temp[0]
            LogPearson3_loc[siteID,windowID] = temp[1]
            LogPearson3_scale[siteID,windowID] = temp[2]

            print '[{},{}] LogPearson3
Success'.format(siteID,windowID)
        except:
            print '[{},{}] LogPearson3 Failed'.format(siteID,windowID)
```

A5.1.2.4 Uncertainty Analysis

While the design flows for 10,20,50,100-y events and corresponding ARIs can be read off from the fitted curves, it is desirable to obtain standard errors or confidence intervals for the design flow and ARI estimates. While there are analytical equations that gives confidence intervals for Pearson-3 quantiles (Maidment 1991; section 18.4; *Handbook of Hydrology*), it is known that the analytical equation only applies for asymptotic region where the fitted curves closely resembles normal or lognormal distribution. This region covers the non-extreme probability

quantiles, say p < 0.95 (less than 20 year return probability). The design frequency of interest is beyond this range and a method that does not require such asymptotic assumption is needed for uncertainty estimation of quantiles for 20-years or more.

General reading of modern literature (post-2000) on "pearson-3 quantile confidence interval" revealed that Monte Carlo simulation is appropriate for this purpose.

Monte Carlo simulation is based on assumption that the annual maxima observations for our sites arose out of a sampling process from stationary probability distributions. For example, WISKI identified that annual maxima of 1122_34 Te Aroha(14d) is best modelled with LogPearson-3 distribution with number of sample of 53 (i.e. 53 years of continuous record). What we have achieved from curve-fitting is that we reduced the hydrological observation into a statistical model. Monte Carlo simulation perceives the 53 observation as a result of pure statistical phenomena and investigates the inherent statistical variations associated with this way of perceiving the observation. It repeats the statistical sampling process to obtain alternate sets of 53 observations, created randomly from the fitted probability distribution. In a sense, it simulates several thousands of parallel universes and measures the statistical variations among these simulations.

For example, random sampling from the fitted distribution from 1122_34 Te Aroha(peak) results in several different sets of 53 data points. These results in different fitted curves. These different curves arising from the random sampling will result in different design curves and ARIs.

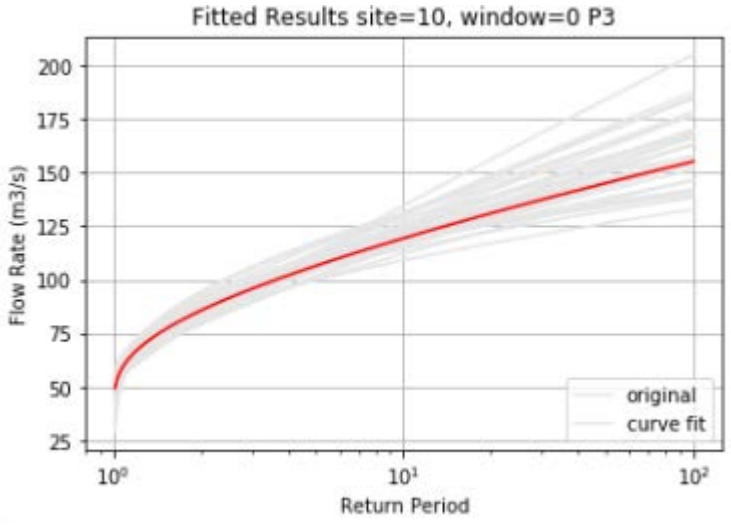


Figure 33: Result of 10 Monte Carlo sampling simulations. 1122_34 Te Aroha(peak). Red=fitted curve on actual observation. Gray=fitted curves on 10 sample sets obtained in Monte Carlo process.

Figure 33 demonstrates the expected statistical variation, i.e. expected uncertainty associated with the probability distribution fitting. In this project, 2,000 sample sets per each site/event duration combination was created based on the estimated distribution parameters obtained by methods described above. It is rather difficult to plot all 2000 curves on a single plot, so 97.5, 75, 25, 0.025 percentiles of the variations of flow at multiple return period (x-axis) values were obtained and plotted. The resulting plot (Figure 34) shows inner and outer band of that statistical variability.

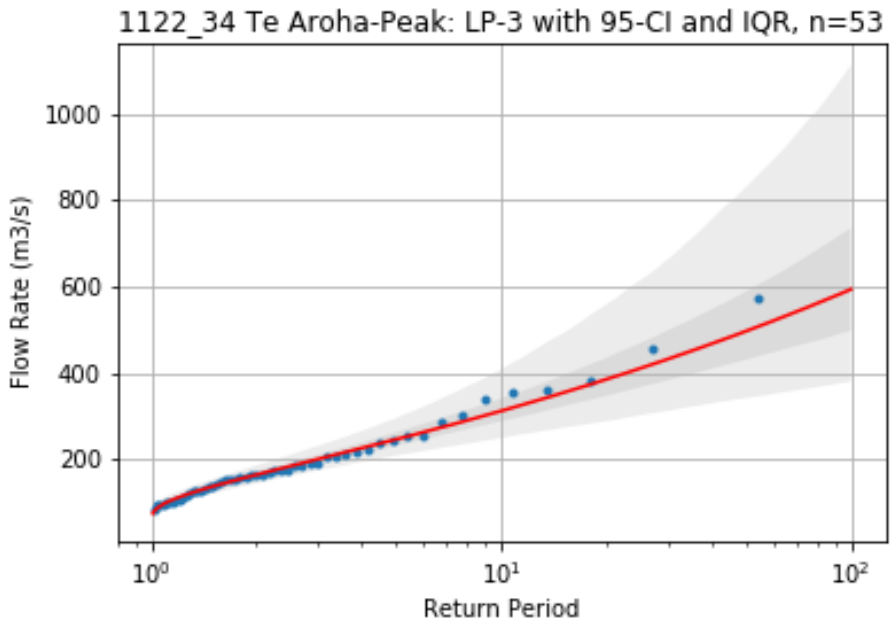


Figure 34: Inner and outer band of statistical variability inherent to LogPearson distribution fit for 1122_34 Te Aroha(peak) data. Outer band = 95% confidence interval band, Inner band = Inter-Quartile Range (IQR) band, Red=fitted distribution on actual data, Blue dots=actual 53 observation.

Python Script

```
def GenerateCI(site,window):
    print '-- Starting {},{} --'.format(site,window)
    n = maxima_dump2[site].iloc[:,window].count()
    dump = []
    for i in range(2000):
        sample =
pearson3.rvs(skew=Pearson3_shape[site,window],loc=Pearson3_loc[site,wi
ndow],scale=Pearson3_scale[site,window],size=n)
        test = pd.Series(sample)
        if (i%200)==0:
            sys.stdout.write('.')
        try:
            dump.append(YearMax2DesignLevels(test,'Pearson3-
curve_fit'))
        except:
            continue

    print '\nCalculate CI points'
    Returns = np.logspace(0.01,2,100)
    Alpha97_5 = []
    Alpha75 = []
    Alpha50 = []
    Alpha25 = []
    Alpha2_5 = []
    for year in Returns:
        sys.stdout.write('.')
        Alpha97_5.append(YearAlphaLevel(year,0.975,dump))
        Alpha75.append(YearAlphaLevel(year,0.75,dump))
        #Alpha50.append(YearAlphaLevel(year,0.5,dump))
        Alpha25.append(YearAlphaLevel(year,0.25,dump))
        Alpha2_5.append(YearAlphaLevel(year,0.025,dump))

    print '\nCreate plots'
    #plt.semilogx(Returns,Alpha50)
    series = maxima_dump2[site].iloc[:,window].copy()
    series.dropna(inplace=True)
    series.sort()
```

```
    xdata = np.linspace(0, 1, len(series)+2)
    xdata = xdata[1:-1]
    fig = plt.figure()
    plt.semilogx(1/(1.0-xdata),series,'.')
    coeffs =
[Pearson3_shape[site,window],Pearson3_loc[site,window],Pearson3_scale[
site,window]]
    plotPDF(coeffs,c='r')

plt.fill_between(Returns,Alpha97_5,Alpha2_5,facecolor='0.3',alpha=0.1)

plt.fill_between(Returns,Alpha75,Alpha25,facecolor='0.3',alpha=0.1)

    plt.grid(True)
    plt.title('{} {}-{}: Pearson-3 with 95-CI and IQR,
n={}'.format(site_list['Site Station
Key'][site],site_list['Name'][site],maxima_dump2[site].iloc[:,window].
name,n))
    plt.xlabel('Return Period')
    plt.ylabel('Flow Rate (m3/s)')
    fig.savefig('Q:/Sungsoo/{},{} Pearson-3.png'.format(site,window))
```

A5.1.3 Reading off design flows and ARIs for April 2017 Event

From the return period plots obtained by following method in section A5.1.2, confidence intervals for design flows and ARIs can be read off. First, the confidence intervals for the design flows were obtained by drawing the vertical segments in the 95% confidence interval band at appropriate x-axis locations (i.e. 10, 20, 50, 100). ARI confidence intervals can be obtained by drawing horizontal segments within the confidence interval bands but the maximum end of confidence intervals are typically extremely large. So, only the minimum end of the confidence interval and the central value, obtained by reading off the red curve was reported.

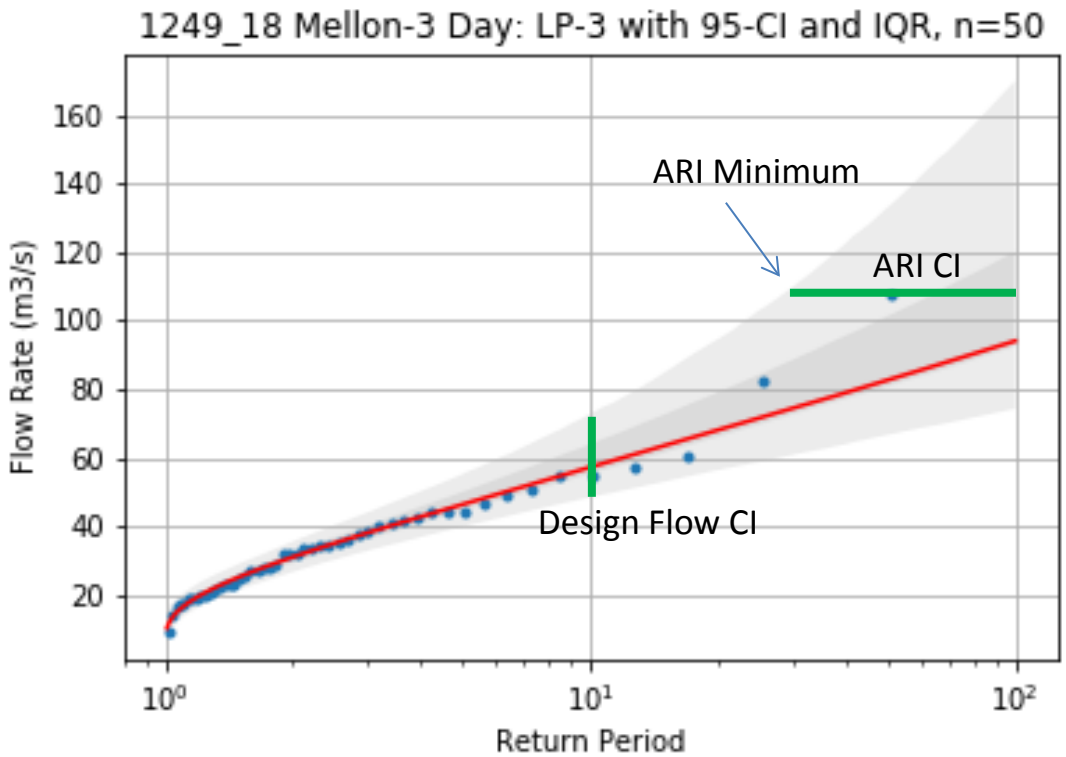


Figure 35: One Example of the frequency analysis plot with uncertainty bands around it.

The readings were automated by the python script. The automated script is given below.

Python script

Step 1. Determine Flow Magnitudes for April 2017 Event at 10 sites

```
to_df = []
SSK = site_list['Site Station Key'][0]
api.timeSeries.getData(path='{}/Flow/Cmd.P'.format(SSK.replace('_','/'
)),frm='2017-03-01',untl='2017-05-
19',transformation='movavg(3day);maximum(7day)')
result = api.timeSeries.data['value.max']
unit='m3/s'
to_df.append(['Apr-2017 Magnitude',None,None,None,result.max(),unit])
```

```
to_df = []
for i in range(11):
    SSK = site_list['Site Station Key'][i]
    name = site_list['Name'][i]
    sys.stdout.write('.')
    for duration in [0,3,7,14,28]:

        if duration == 0:
            dur_str = 'Peak'
            if i==8:
                unit = 'm'

api.timeSeries.getData(path='{}/S/Cmd.P'.format(SSK.replace('_','/')),
frm='2017-03-01',untl='2017-05-10',transformation='maximum(7day)')
                result = api.timeSeries.data['value.max']
                to_df.append([i,SSK,name,dur_str,'Apr-2017
Magnitude',None,None,None,result.max(),unit])
            else:
                unit = 'm3/s'

api.timeSeries.getData(path='{}/Flow/Cmd.P'.format(SSK.replace('_','/'
)),frm='2017-03-01',untl='2017-05-10',transformation='maximum(7day)')
                result = api.timeSeries.data['value.max']
                to_df.append([i,SSK,name,dur_str,'Apr-2017
Magnitude',None,None,None,result.max(),unit])
        else:
            if duration == 3:
                dur_str = '72h'
            else:
                dur_str = '{}d'.format(duration)

            if i==8:
                unit = 'm'

api.timeSeries.getData(path='{}/S/Cmd.P'.format(SSK.replace('_','/')),
frm='2017-03-01',untl='2017-05-
10',transformation='movavg({}day);maximum(7day)'.format(duration))
                result = api.timeSeries.data['value.max']
                to_df.append([i,SSK,name,dur_str,'Apr-2017
Magnitude',None,None,None,result.max(),unit])
            else:
                unit = 'm3/s'

api.timeSeries.getData(path='{}/Flow/Cmd.P'.format(SSK.replace('_','/'
```

```
)),frm='2017-03-01',untl='2017-05-
10',transformation='movavg({}day);maximum(7day)'.format(duration))
                result = api.timeSeries.data['value.max']
                to_df.append([i,SSK,name,dur_str,'Apr-2017
Magnitude',None,None,None,result.max(),unit])
mag_test=pd.DataFrame(to_df,columns=['ID','Site Station Key','Site
Name','duration','Stats
Name','param','unit1','alpha','value','unit2'])
```

Step 2. Define Confidence Interval Reading function calls for Pearson-3 distribution

```
def YearAlphaLevel(returnPeriod,alpha,dump_coeffs):
    '''
    Dump_coeff is the list of 3 parameters, possibly in 2,000 sample
sets out of Monte Carlo sampling process.
    '''
    dump_design_flows = []
    for coeffs in dump_coeffs:
        design_flow = pearson3.ppf(1-1.0/returnPeriod, coeffs[0],
loc=coeffs[1], scale=coeffs[2])
        dump_design_flows.append(design_flow)
    n = len(dump_design_flows)
    index_to_read = int(round(n*alpha))
    sorted_flows = np.sort(np.array(dump_design_flows))
    return sorted_flows[index_to_read]

def YearSE(returnPeriod,dump_coeffs):
    '''
    Dump_coeff is the list of 3 parameters, possibly in 10,000 sample
sets out of Monte Carlo sampling process.
    '''
    dump_design_flows = []
    for coeffs in dump_coeffs:
        design_flow = pearson3.ppf(1-1.0/returnPeriod, coeffs[0],
loc=coeffs[1], scale=coeffs[2])
        dump_design_flows.append(design_flow)
    return np.std(dump_design_flows,ddof=1)

def LevelAlphaYear(flow,alpha,dump_coeffs):
    '''
    Dump_coeff is the list of 3 parameters, possibly in 10,000 sample
sets out of Monte Carlo sampling process.
    '''
    dump_recurrence_interval = []
    for coeffs in dump_coeffs:
        prob = pearson3.cdf(flow, coeffs[0], loc=coeffs[1],
scale=coeffs[2])
        dump_recurrence_interval.append(1.0/(1.0-prob))
    n = len(dump_recurrence_interval)
    index_to_read = int(round(n*alpha))
    sorted_year = np.sort(np.array(dump_recurrence_interval))
    return sorted_year[index_to_read]

def LevelSE(flow,dump_coeffs):
    '''
```

```
    Dump_coeff is the list of 3 parameters, possibly in 10,000 sample
sets out of Monte Carlo sampling process.
    '''
    dump_recurrence_interval = []
    for coeffs in dump_coeffs:
        prob = pearson3.cdf(flow, coeffs[0], loc=coeffs[1],
scale=coeffs[2])
        dump_recurrence_interval.append(1.0/(1.0-prob))
    return np.std(dump_recurrence_interval,ddof=1)
```

Step 3. Read off Design Flow CIs and ARI CIs for Pearson-3 distribution sites

```
import sys

def ExtractCI(site,window,flowMag=30,unit='m3/s',N=2000,Returns =
[10,20,50,100]):
    print '-- Starting P3 {},{} --'.format(site,window)
    n = maxima_dump2[site].iloc[:,window].count()
    dump = []
    for i in range(N):
        sample =
pearson3.rvs(skew=Pearson3_shape[site,window],loc=Pearson3_loc[site,wi
ndow],scale=Pearson3_scale[site,window],size=n)
        test = pd.Series(sample)
        if (i%200)==0:
            sys.stdout.write('.')

        try:
            dump.append(YearMax2DesignLevels(test,'Pearson3-
curve_fit'))
        except:
            continue

    print '\nCalculate CI points'
    to_df = []
    for year in Returns:
        sys.stdout.write('.')
        to_df.append(['Design Flow
CI',year,'year',0.975,YearAlphaLevel(year,0.975,dump),unit])
        to_df.append(['Design Flow
CI',year,'year',0.75,YearAlphaLevel(year,0.75,dump),unit])
        to_df.append(['Design Flow
CI',year,'year',0.5,YearAlphaLevel(year,0.5,dump),unit])
        to_df.append(['Design Flow
CI',year,'year',0.25,YearAlphaLevel(year,0.25,dump),unit])
        to_df.append(['Design Flow
CI',year,'year',0.025,YearAlphaLevel(year,0.025,dump),unit])
        to_df.append(['Design Flow
SE',year,'year',None,YearSE(year,dump),unit])

coeffs=[Pearson3_shape[site,window],Pearson3_loc[site,window],Pearson3
_scale[site,window]]
        design_flow = pearson3.ppf(1-1.0/year, coeffs[0],
loc=coeffs[1], scale=coeffs[2])
        to_df.append(['Design Flow
fit',year,'year',None,design_flow,unit])
```

```
    print '\nCalculate ARI'
    to_df.append(['ARI
CI',flowMag,unit,0.975,LevelAlphaYear(flowMag,0.975,dump),'year'])
    to_df.append(['ARI
CI',flowMag,unit,0.75,LevelAlphaYear(flowMag,0.75,dump),'year'])
    to_df.append(['ARI
CI',flowMag,unit,0.5,LevelAlphaYear(flowMag,0.5,dump),'year'])
    to_df.append(['ARI
CI',flowMag,unit,0.25,LevelAlphaYear(flowMag,0.25,dump),'year'])
    to_df.append(['ARI
CI',flowMag,unit,0.025,LevelAlphaYear(flowMag,0.025,dump),'year'])
    to_df.append(['ARI
SE',flowMag,unit,None,LevelSE(flowMag,dump),'year'])

    # ARI from fitted curve

coeffs=[Pearson3_shape[site,window],Pearson3_loc[site,window],Pearson3
_scale[site,window]]
    prob = pearson3.cdf(flowMag, coeffs[0], loc=coeffs[1],
scale=coeffs[2])
    to_df.append(['ARI fit',flowMag,unit,None,1.0/(1.0-prob),'year'])

    df = pd.DataFrame(to_df,columns=['Stats
Name','param','unit1','alpha','value','unit2'])
    return df
```

Step 4. Define Confidence Interval Reading function calls for LogPearson-3 distribution

```
def LogYearAlphaLevel(returnPeriod,alpha,dump_coeffs):
    '''
    Dump_coeff is the list of 3 parameters, possibly in 2,000 sample
sets out of Monte Carlo sampling process.
    '''
    dump_design_flows = []
    for coeffs in dump_coeffs:
        design_flow = np.exp(pearson3.ppf(1-1.0/returnPeriod,
coeffs[0], loc=coeffs[1], scale=coeffs[2]))
        dump_design_flows.append(design_flow)
    n = len(dump_design_flows)
    index_to_read = int(round(n*alpha))
    sorted_flows = np.sort(np.array(dump_design_flows))
    return sorted_flows[index_to_read]

def LogYearSE(returnPeriod,dump_coeffs):
    '''
    Dump_coeff is the list of 3 parameters, possibly in 10,000 sample
sets out of Monte Carlo sampling process.
    '''
    dump_design_flows = []
    for coeffs in dump_coeffs:
        design_flow = np.exp(pearson3.ppf(1-1.0/returnPeriod,
coeffs[0], loc=coeffs[1], scale=coeffs[2]))
        dump_design_flows.append(design_flow)
    return np.std(dump_design_flows,ddof=1)
```

```
def LogLevelAlphaYear(flow,alpha,dump_coeffs):
    '''
    Dump_coeff is the list of 3 parameters, possibly in 10,000 sample
sets out of Monte Carlo sampling process.
    '''
    dump_recurrence_interval = []
    for coeffs in dump_coeffs:
        prob = pearson3.cdf(np.log(flow), coeffs[0], loc=coeffs[1],
scale=coeffs[2])
        dump_recurrence_interval.append(1.0/(1.0-prob))
    n = len(dump_recurrence_interval)
    index_to_read = int(round(n*alpha))
    sorted_year = np.sort(np.array(dump_recurrence_interval))
    return sorted_year[index_to_read]

def LogLevelSE(flow,dump_coeffs):
    '''
    Dump_coeff is the list of 3 parameters, possibly in 10,000 sample
sets out of Monte Carlo sampling process.
    '''
    dump_recurrence_interval = []
    for coeffs in dump_coeffs:
        prob = pearson3.cdf(np.log(flow), coeffs[0], loc=coeffs[1],
scale=coeffs[2])
        dump_recurrence_interval.append(1.0/(1.0-prob))
    return np.std(dump_recurrence_interval,ddof=1)
```

Step 5. Read off Design Flow CIs and ARI CIs for LogPearson-3 distribution sites

```
import sys

def LogExtractCI(site,window,flowMag=30,unit='m3/s',N=2000,Returns =
[10,20,50,100]):
    print '-- Starting LP3 {},{} --'.format(site,window)
    n = maxima_dump2[site].iloc[:,window].count()
    dump = []
    for i in range(N):
        sample =
pearson3.rvs(skew=LogPearson3_shape[site,window],loc=LogPearson3_loc[s
ite,window],scale=LogPearson3_scale[site,window],size=n)
        test = pd.Series(np.exp(sample))
        if (i%200)==0:
            sys.stdout.write('.')

        try:
            dump.append(YearMax2DesignLevels(test,'LogPearson3-
curve_fit'))
        except:
            continue

    print '\nCalculate CI points'
    to_df = []
    for year in Returns:
        sys.stdout.write('.')
        to_df.append(['Design Flow
CI',year,'year',0.975,LogYearAlphaLevel(year,0.975,dump),unit])
```

```
        to_df.append(['Design Flow
CI',year,'year',0.75,LogYearAlphaLevel(year,0.75,dump),unit])
        to_df.append(['Design Flow
CI',year,'year',0.5,LogYearAlphaLevel(year,0.5,dump),unit])
        to_df.append(['Design Flow
CI',year,'year',0.25,LogYearAlphaLevel(year,0.25,dump),unit])
        to_df.append(['Design Flow
CI',year,'year',0.025,LogYearAlphaLevel(year,0.025,dump),unit])
        to_df.append(['Design Flow
SE',year,'year',None,LogYearSE(year,dump),unit])


coeffs=[LogPearson3_shape[site,window],LogPearson3_loc[site,window],Lo
gPearson3_scale[site,window]]
        design_flow = np.exp(pearson3.ppf(1-1.0/year, coeffs[0],
loc=coeffs[1], scale=coeffs[2]))
        to_df.append(['Design Flow
fit',year,'year',None,design_flow,unit])


    print '\nCalculate ARI'
    to_df.append(['ARI
CI',flowMag,unit,0.975,LogLevelAlphaYear(flowMag,0.975,dump),'year'])
    to_df.append(['ARI
CI',flowMag,unit,0.75,LogLevelAlphaYear(flowMag,0.75,dump),'year'])
    to_df.append(['ARI
CI',flowMag,unit,0.5,LogLevelAlphaYear(flowMag,0.5,dump),'year'])
    to_df.append(['ARI
CI',flowMag,unit,0.25,LogLevelAlphaYear(flowMag,0.25,dump),'year'])
    to_df.append(['ARI
CI',flowMag,unit,0.025,LogLevelAlphaYear(flowMag,0.025,dump),'year'])
    to_df.append(['ARI
SE',flowMag,unit,None,LogLevelSE(flowMag,dump),'year'])

    # ARI from fitted curve

coeffs=[LogPearson3_shape[site,window],LogPearson3_loc[site,window],Lo
gPearson3_scale[site,window]]
    prob = pearson3.cdf(np.log(flowMag), coeffs[0], loc=coeffs[1],
scale=coeffs[2])
    to_df.append(['ARI fit',flowMag,unit,None,1.0/(1.0-prob),'year'])

    df = pd.DataFrame(to_df,columns=['Stats
Name','param','unit1','alpha','value','unit2'])
    return df
```

Step 6. Package all reporting information and save in a csv file

```
df_dump = []
dur_str_list = ['Peak','72h','7d','14d','28d']
for site in range(11):
    for window in range(5):
        magnitude = mag_test[(mag_test['ID']==site) &
(mag_test['duration']==dur_str_list[window])]['value'].tolist()[0]
```

```
        if (np.abs(LogPearson3_shape[site,window]) > 1e-10) and
(np.abs(LogPearson3_loc[site,window]) > 1e-10):
            if site==8:
                LP3_df =
LogExtractCI(site,window,flowMag=magnitude,unit='m',N=2000)
            else:
                LP3_df =
LogExtractCI(site,window,flowMag=magnitude,unit='m3/s',N=2000)
        if (np.abs(Pearson3_shape[site,window]) > 1e-10) and
(np.abs(Pearson3_loc[site,window]) > 1e-10):
            if site==8:
                P3_df =
ExtractCI(site,window,flowMag=magnitude,unit='m',N=2000)
            else:
                P3_df =
ExtractCI(site,window,flowMag=magnitude,unit='m3/s',N=2000)


        LP3_df['ID'] = site
        LP3_df['Site Station Key'] = site_list['Site Station
Key'][site]
        LP3_df['Site Name'] = site_list['Name'][site]
        LP3_df['duration'] = dur_str_list[window]
        LP3_df['distribution'] = 'LP3'

        P3_df['ID'] = site
        P3_df['Site Station Key'] = site_list['Site Station
Key'][site]
        P3_df['Site Name'] = site_list['Name'][site]
        P3_df['duration'] = dur_str_list[window]
        P3_df['distribution'] = 'P3'

        df_dump.append(LP3_df)
        df_dump.append(P3_df)
print 'Done'
```

Step 7. Create Reporting Tables, Design Flow CI then ARI Tables

```
def distributionType(site):
    if site_list['Distribution'][site]=='LogPearson3':
        return 'LP3'
    else:
        return 'P3'

def LowerDesignCI(site,window,year):
    candidate = ztest[(ztest['ID']==site) & (ztest['Stats
Name']=='Design Flow CI') & (ztest['duration']==dur_str_list[window])
& (ztest['distribution']==distributionType(site))]
    return candidate[(candidate['param']==year) &
(candidate['alpha']==0.025)]['value'].tolist()[0]

def UpperDesignCI(site,window,year):
    candidate = ztest[(ztest['ID']==site) & (ztest['Stats
Name']=='Design Flow CI') & (ztest['duration']==dur_str_list[window])
& (ztest['distribution']==distributionType(site))]
    return candidate[(candidate['param']==year) &
(candidate['alpha']==0.975)]['value'].tolist()[0]
```

```
def DesignSE(site,window,year):
    candidate = ztest[(ztest['ID']==site) & (ztest['Stats
Name']=='Design Flow SE') & (ztest['duration']==dur_str_list[window])
& (ztest['distribution']==distributionType(site))]
    return candidate[(candidate['param']==year)]['value'].tolist()[0]

def DesignCenter(site,window,year):
    candidate = ztest[(ztest['ID']==site) & (ztest['Stats
Name']=='Design Flow fit') & (ztest['duration']==dur_str_list[window])
& (ztest['distribution']==distributionType(site))]
    return candidate[(candidate['param']==year)]['value'].tolist()[0]

def ARILowerCI(site,window):
    candidate = ztest[(ztest['ID']==site) & (ztest['Stats Name']=='ARI
CI') & (ztest['duration']==dur_str_list[window]) &
(ztest['distribution']==distributionType(site))]
    return candidate[(candidate['alpha']==0.025)]['value'].tolist()[0]

def ARICenter(site,window):
    candidate = ztest[(ztest['ID']==site) & (ztest['Stats Name']=='ARI
fit') & (ztest['duration']==dur_str_list[window]) &
(ztest['distribution']==distributionType(site))]
    return candidate['value'].tolist()[0]

def Magnitude(site,window):
    candidate = ztest[(ztest['ID']==site) & (ztest['Stats
Name']=='Apr-2017 Magnitude') &
(ztest['duration']==dur_str_list[window])]
    return candidate['value'].tolist()[0]
```

```
ARI_dump = []
for site in range(11):
    ARI_dump.append([site_list['Name'][site],site_list['Site Station
Key'][site],Magnitude(site,window)

ARILowerCI(site,0),ARILowerCI(site,1),ARILowerCI(site,2),ARILowerCI(si
te,3),ARILowerCI(site,4),distributionType(site)])
ARILowerTable = pd.DataFrame(ARI_dump,columns=['Name','Site Station
Key','Peak','72h','7d','14d','28d','dist'])

ARI_dump = []
for site in range(11):
    ARI_dump.append([site_list['Name'][site],site_list['Site Station
Key'][site],

ARICenter(site,0),ARICenter(site,1),ARICenter(site,2),ARICenter(site,3
),ARICenter(site,4),distributionType(site)])
ARICentralTable = pd.DataFrame(ARI_dump,columns=['Name','Site Station
Key','Peak','72h','7d','14d','28d','dist'])
```

```
Design_flow_dump = []
def DesignCI(site,window,year):
```

```
    digits=np.log10(LowerDesignCI(site,window,year))+1
    if digits < 2:
        return '{:.1f}-
{:.1f}'.format(LowerDesignCI(site,window,year),UpperDesignCI(site,wind
ow,year))
    else:
        return '{:.0f}-
{:.0f}'.format(LowerDesignCI(site,window,year),UpperDesignCI(site,wind
ow,year))

for site in range(11):
    Design_flow_dump.append([site_list['Name'][site],site_list['Site
Station Key'][site],10,

DesignCI(site,0,10),DesignCI(site,1,10),DesignCI(site,2,10),DesignCI(s
ite,3,10),DesignCI(site,4,10),distributionType(site)])

    Design_flow_dump.append([site_list['Name'][site],site_list['Site
Station Key'][site],20,

DesignCI(site,0,20),DesignCI(site,1,20),DesignCI(site,2,20),DesignCI(s
ite,3,20),DesignCI(site,4,20),distributionType(site)])

    Design_flow_dump.append([site_list['Name'][site],site_list['Site
Station Key'][site],50,

DesignCI(site,0,50),DesignCI(site,1,50),DesignCI(site,2,50),DesignCI(s
ite,3,50),DesignCI(site,4,50),distributionType(site)])

    Design_flow_dump.append([site_list['Name'][site],site_list['Site
Station Key'][site],100,

DesignCI(site,0,100),DesignCI(site,1,100),DesignCI(site,2,100),DesignC
I(site,3,100),DesignCI(site,4,100),distributionType(site)])

DesignFlowCITable =
pd.DataFrame(Design_flow_dump,columns=['Name','Site Station
Key','Return(y)','Peak','72h','7d','14d','28d','dist'])
```

A5.2 Results

A5.2.1 Reporting tables

Design flow - 95% Confidence Intervals. Unit: m3/s, except for Maukoro, where unit=m

Name	Site Station Key	Return(y)	Peak	72h	7d	14d	28d	dist
Te Kuiti	414_13	10	81-125	40-58	30-41	24-33	19-27	LP3
Te Kuiti	414_13	20	92-162	45-69	33-49	27-40	20-33	LP3
Te Kuiti	414_13	50	106-228	50-89	36-63	30-52	23-43	LP3
Te Kuiti	414_13	100	116-282	54-107	39-76	32-62	24-53	LP3
Otorohanga	1191_13	10	304-434	227-296	172-230	138-180	107-153	P3
Otorohanga	1191_13	20	334-511	248-335	187-264	150-205	117-180	P3
Otorohanga	1191_13	50	369-612	272-383	204-307	163-236	128-216	P3
Otorohanga	1191_13	100	393-686	287-418	214-338	172-259	136-242	P3
Whatawhata	1191_11	10	575-792	541-742	461-614	384-513	304-403	P3
Whatawhata	1191_11	20	628-925	588-862	502-709	419-592	330-463	P3

Whatawhata	1191_11	50	687-1094	646-1020	549-834	458-695	359-545	P3
Whatawhata	1191_11	100	727-1220	682-1139	578-928	486-770	379-608	P3
Hamilton	1131_64	10	611-781	554-721	520-680	480-596	443-542	LP3
Hamilton	1131_64	20	658-900	599-849	565-806	518-681	473-610	LP3
Hamilton	1131_64	50	715-1078	652-1047	615-992	561-812	508-716	LP3
Hamilton	1131_64	100	755-1236	694-1222	650-1164	590-924	532-802	LP3
Ngaruawahia	1131_103	10	1009-1159	969-1124	872-1020	781-941	686-811	P3
Ngaruawahia	1131_103	20	1066-1258	1028-1229	927-1115	833-1049	731-897	P3
Ngaruawahia	1131_103	50	1129-1388	1094-1367	985-1246	892-1189	779-1008	P3
Ngaruawahia	1131_103	100	1173-1480	1139-1465	1025-1335	930-1300	811-1089	P3
Control Structure	1131_165	10	1177-1413	1168-1399	1127-1374	1054-1303	938-1170	P3
Control Structure	1131_165	20	1253-1555	1244-1533	1204-1518	1131-1444	1006-1302	P3
Control Structure	1131_165	50	1339-1730	1329-1703	1289-1711	1215-1638	1082-1480	P3
Control Structure	1131_165	100	1393-1864	1383-1830	1343-1855	1269-1783	1132-1619	P3
Paeroa-Tahuna Rd Br	749_15	10	107-154	78-103	60-76	48-62	37-47	P3
Paeroa-Tahuna Rd Br	749_15	20	122-185	86-120	65-87	53-72	40-53	P3
Paeroa-Tahuna Rd Br	749_15	50	139-229	95-142	71-101	58-85	44-62	P3
Paeroa-Tahuna Rd Br	749_15	100	151-261	101-158	75-111	61-95	46-68	P3
Mellon	1249_18	10	59-102	49-73	40-58	31-47	24-35	LP3
Mellon	1249_18	20	71-146	57-96	46-73	36-59	28-43	LP3
Mellon	1249_18	50	86-236	67-135	53-101	42-79	32-58	LP3
Mellon	1249_18	100	98-329	75-173	59-127	46-99	35-72	LP3
Maukoro (WL only)	749_12	10	3.0-3.3	2.8-3.1	2.7-3.1	2.5-3.1	2.1-2.6	P3
Maukoro (WL only)	749_12	20	3.1-3.5	2.9-3.3	2.8-3.3	2.6-3.5	2.3-2.9	P3
Maukoro (WL only)	749_12	50	3.2-3.8	3.0-3.5	2.9-3.6	2.8-4.0	2.4-3.3	P3
Maukoro (WL only)	749_12	100	3.3-4.0	3.1-3.7	3.0-3.9	2.9-4.4	2.5-3.6	P3
Karangahake	619_16	10	659-971	252-381	192-344	147-268	104-181	LP3
Karangahake	619_16	20	772-1254	300-501	237-502	184-403	128-265	LP3
Karangahake	619_16	50	919-1743	362-703	293-813	234-681	161-432	LP3
Karangahake	619_16	100	1030-2200	408-912	339-1184	275-991	186-619	LP3
Te Aroha	1122_34	10	253-408	184-241	138-174	109-136	88-111	LP3
Te Aroha	1122_34	20	293-559	204-287	151-201	119-158	95-129	LP3
Te Aroha	1122_34	50	344-842	227-358	165-242	130-191	104-155	LP3
Te Aroha	1122_34	100	386-1116	244-422	176-275	138-221	109-178	LP3

Note: dist column = distribution used for the analysis

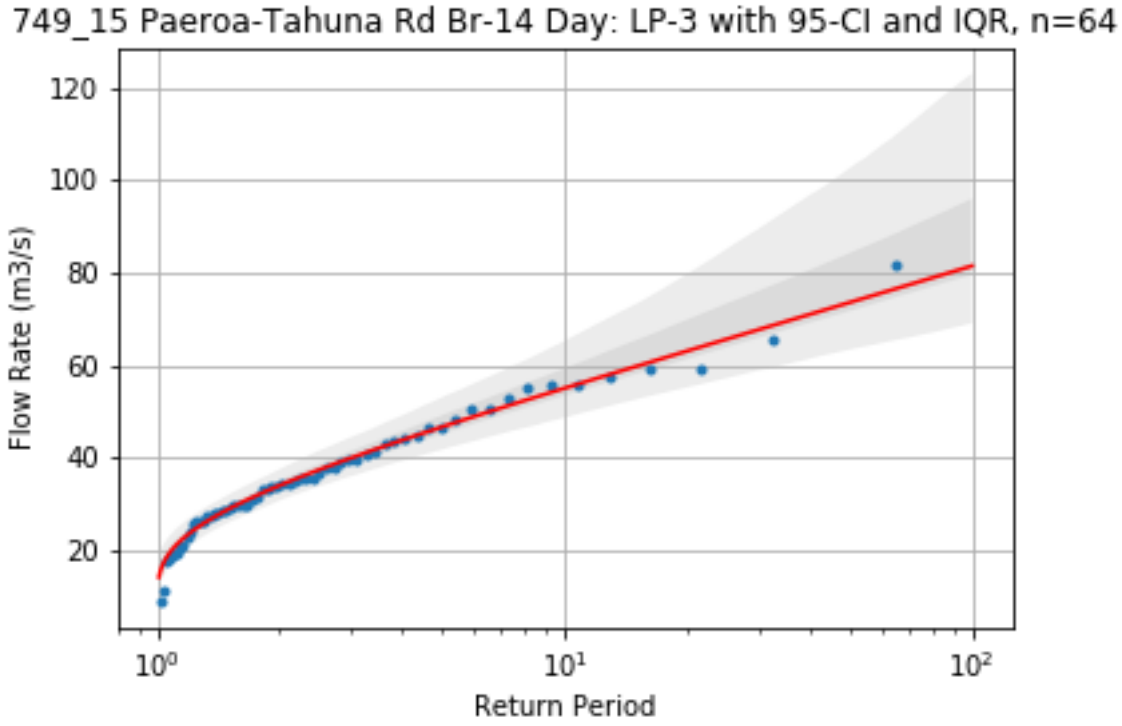
Minimum ARI values: lower end of 95% confidence interval. unit: years

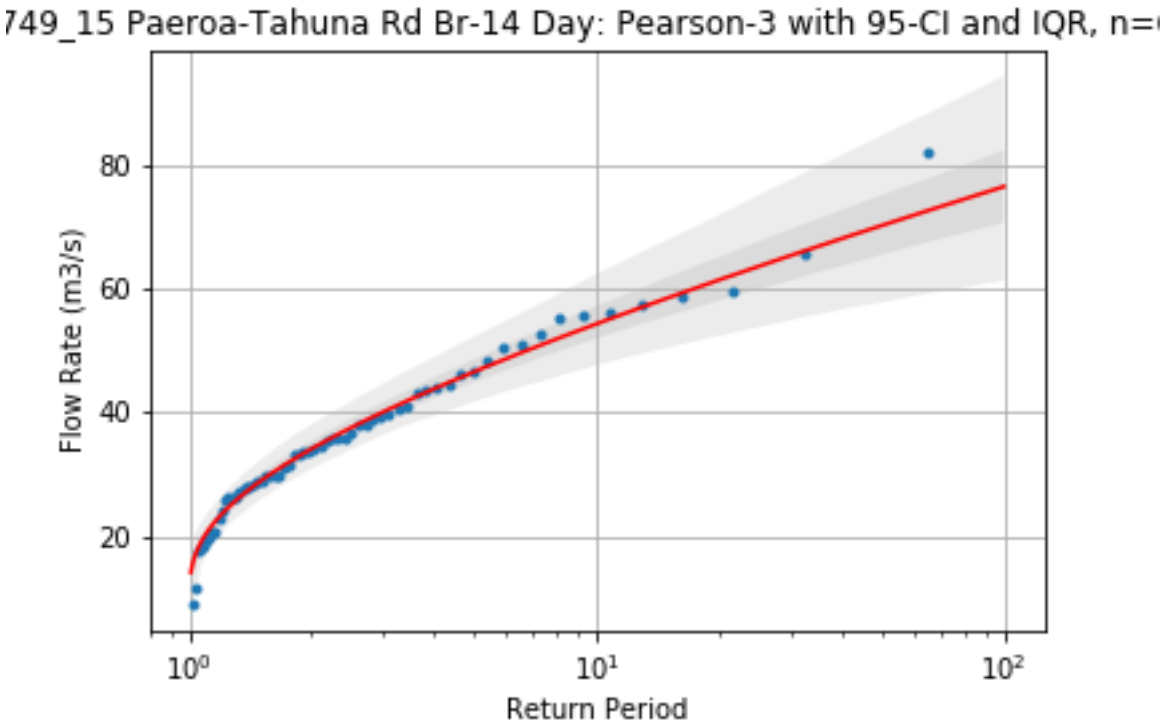
Name	Site Station Key	Peak	72h	7d	14d	28d	dist
Te Kuiti	414_13	2.8	1.9	1.8	2.3	1.7	LP3
Otorohanga	1191_13	1.6	1.5	1.3	1.7	1.4	P3
Whatawhata	1191_11	3.6	3.2	2.3	3.4	2.3	P3
Hamilton	1131_64	5.2	5.6	5.2	7.0	5.2	LP3
Ngaruawahia	1131_103	6.5	6.2	5.2	7.6	5.4	P3
Control Structure	1131_165	6.4	6.2	6.3	7.8	6.2	P3
Paeroa-Tahuna Rd Br	749_15	22	33	25	40	18	P3
Mellon	1249_18	18	27	16	14	9.0	LP3
Maukoro (WL only)	749_12	11	17	11	7.9	7.6	P3
Karangahake	619_16	2.3	1.4	1.4	1.4	1.4	LP3
Te Aroha	1122_34	7.6	9.5	9.2	10	8.2	LP3

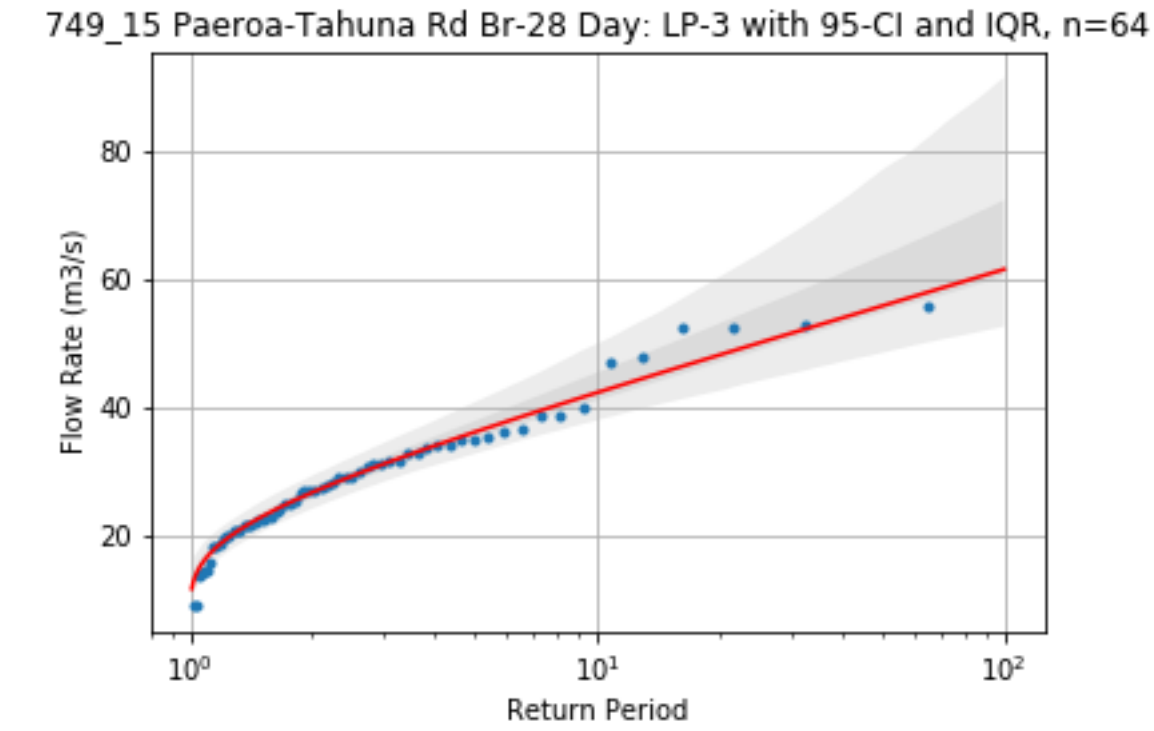
Central ARI values (on red curve) unit: years

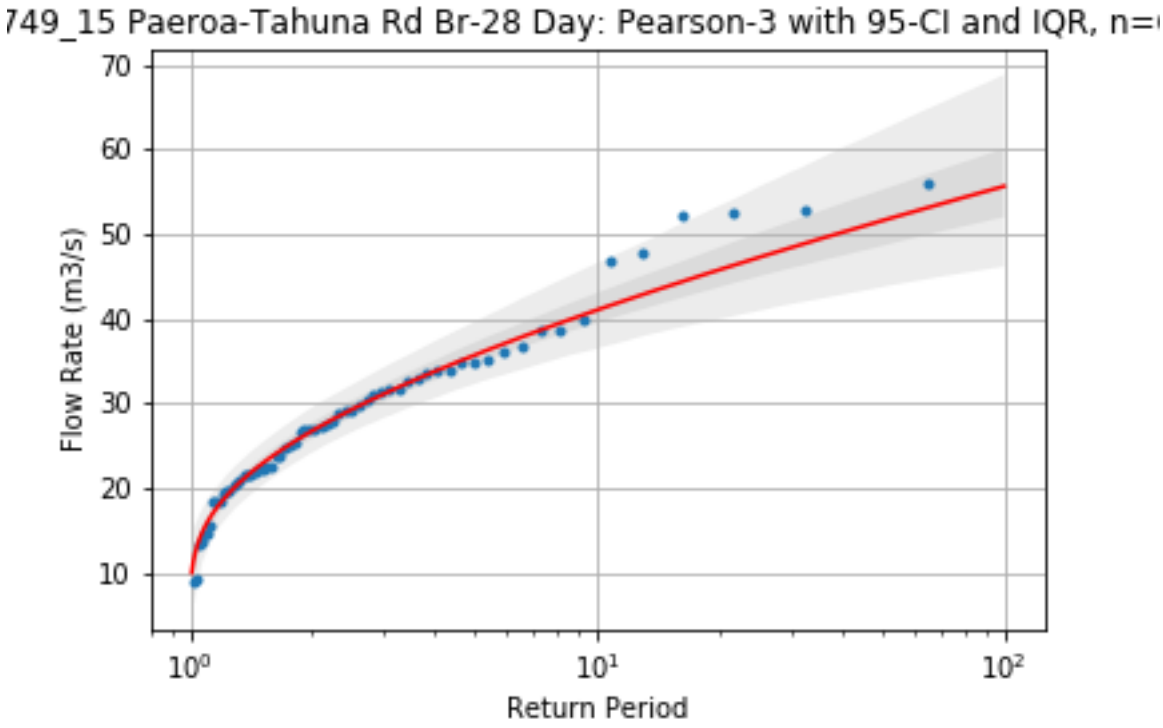
Name	Site Station Key	Peak	72h	7d	14d	28d	dist
Te Kuiti	414_13	4.3	2.6	2.3	3.2	2.2	LP3
Otorohanga	1191_13	2.1	1.9	1.6	2.2	1.7	P3
Whatawhata	1191_11	5.9	4.9	3.3	5.1	3.3	P3
Hamilton	1131_64	10	11	9.8	16	9.9	LP3
Ngaruawahia	1131_103	13	11	8.7	15	8.9	P3
Control Structure	1131_165	15	14	15	21	14	P3
Paeroa-Tahuna Rd Br	749_15	67	126	91	184	56	P3
Mellon	1249_18	76	225	71	52	23	LP3
Maukoro (WL only)	749_12	27	98	41	20	21	P3
Karangahake	619_16	2.9	1.6	1.6	1.6	1.6	LP3
Te Aroha	1122_34	16	24	24	27	18	LP3

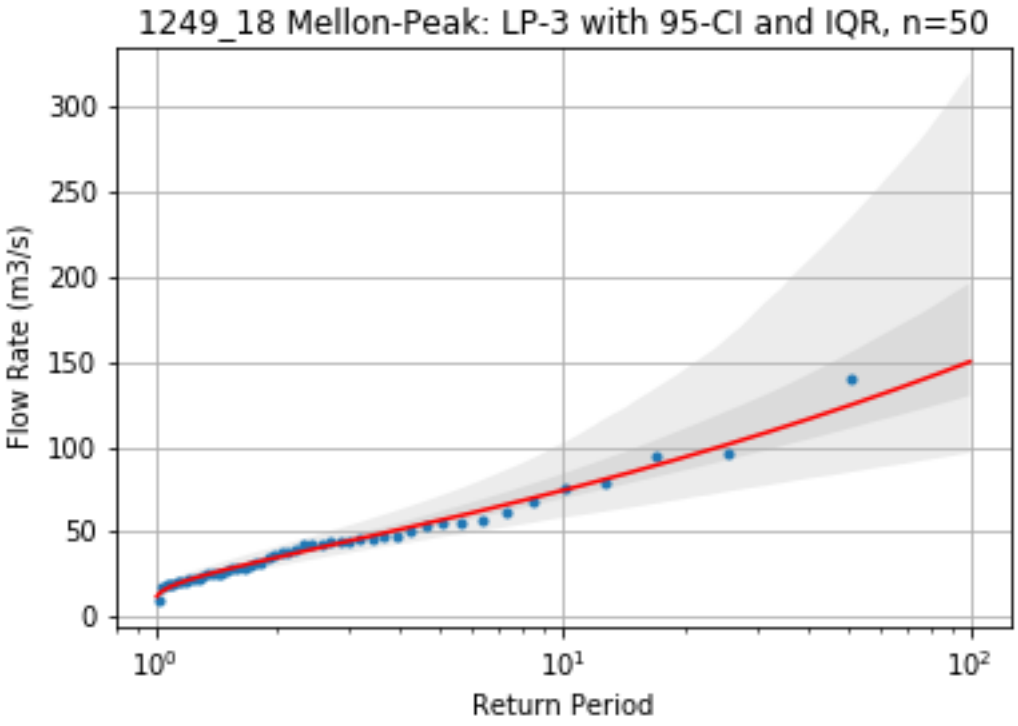
A5.2.2 Return period plots

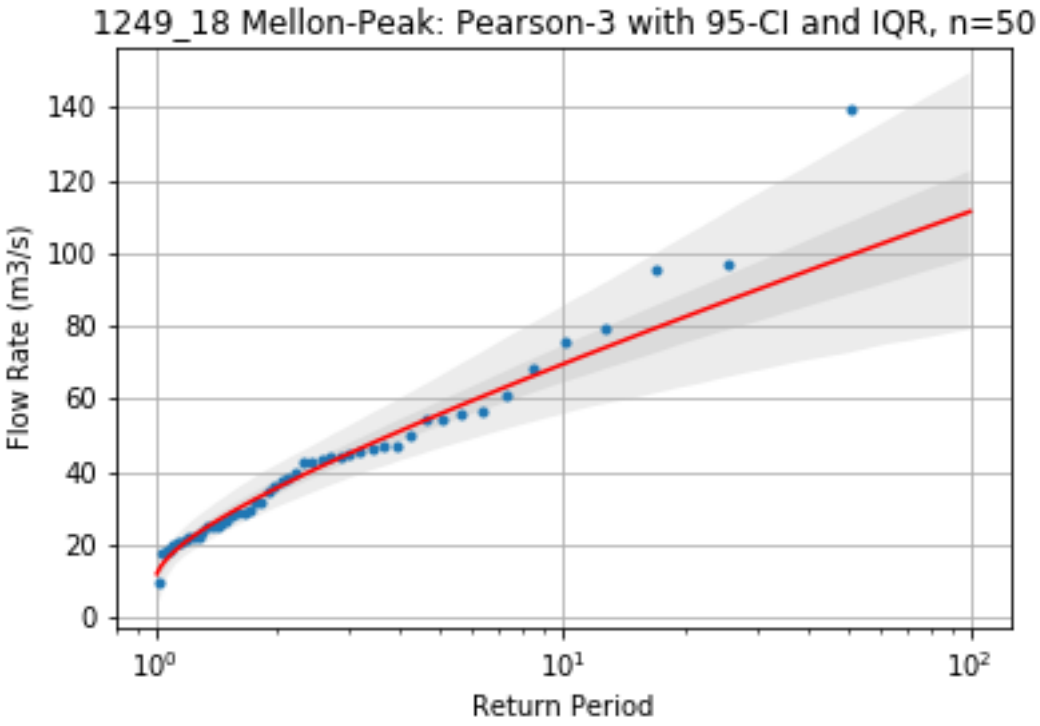


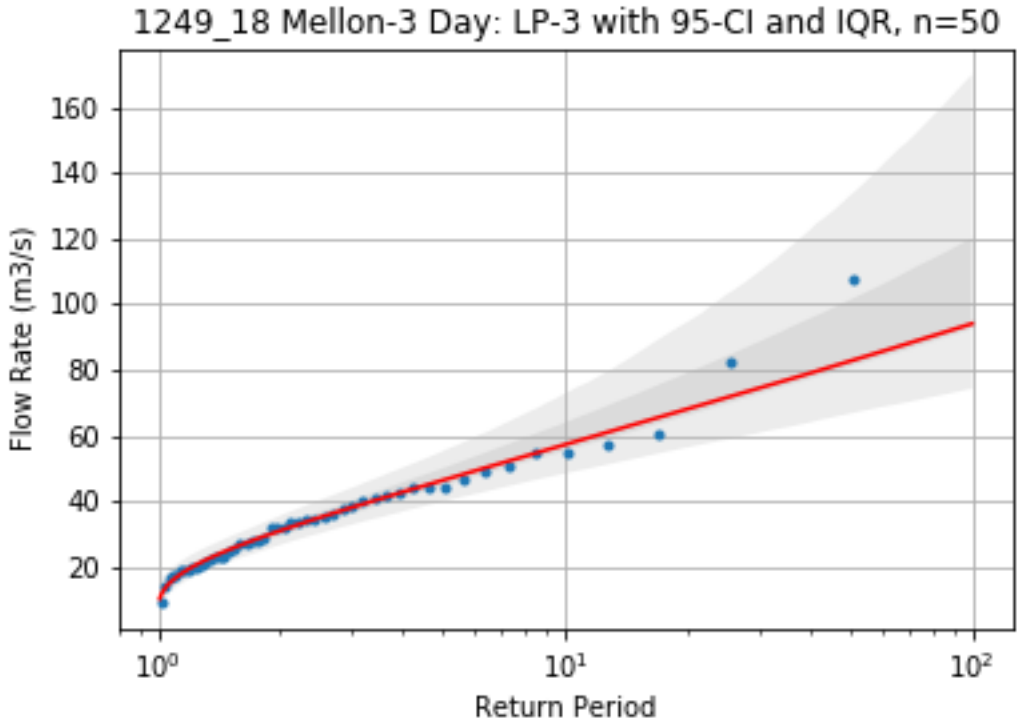


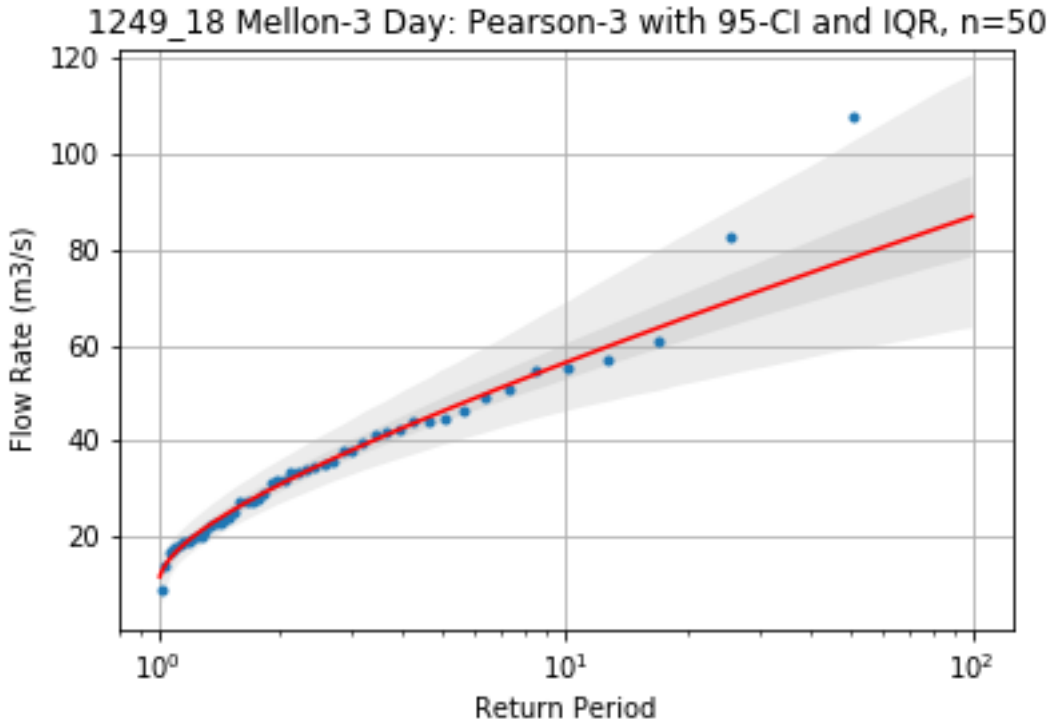

749_15 Paeroa-Tahuna Rd Br-28 Day: LP-3 with 95-CI and IQR, n=64
Flow Rate (m3/s)
80
60
40
20
10^0
10^1
10^2
Return Period

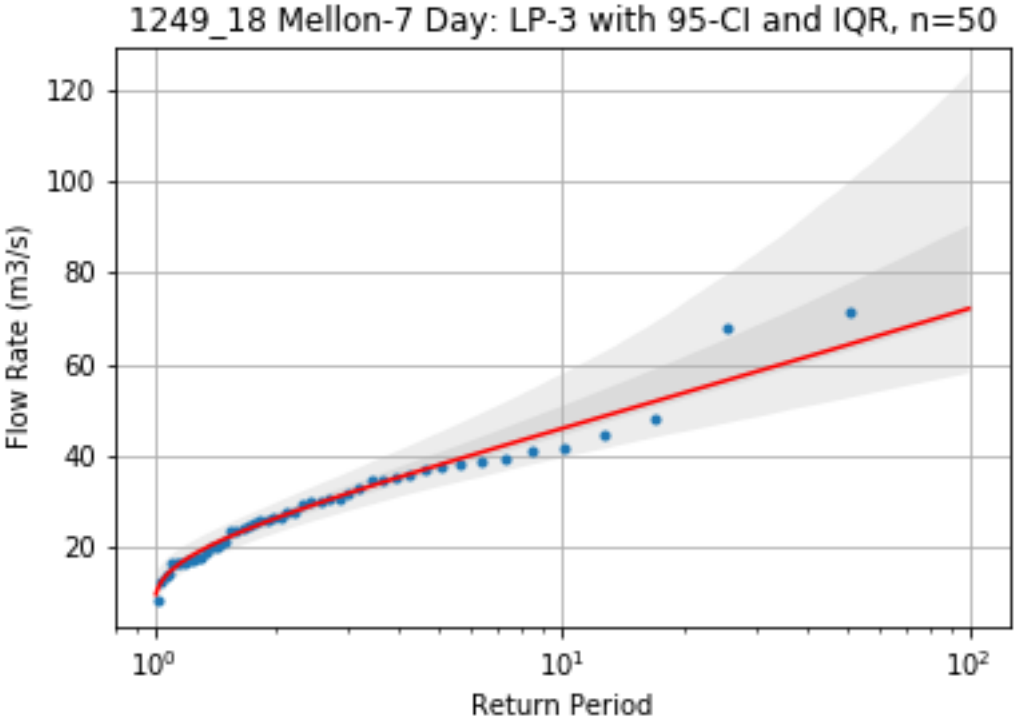

749_15 Paeroa-Tahuna Rd Br-28 Day: Pearson-3 with 95-CI and IQR, n=
Flow Rate (m3/s)
70
60
50
40
30
20
10
10^0
10^1
10^2
Return Period

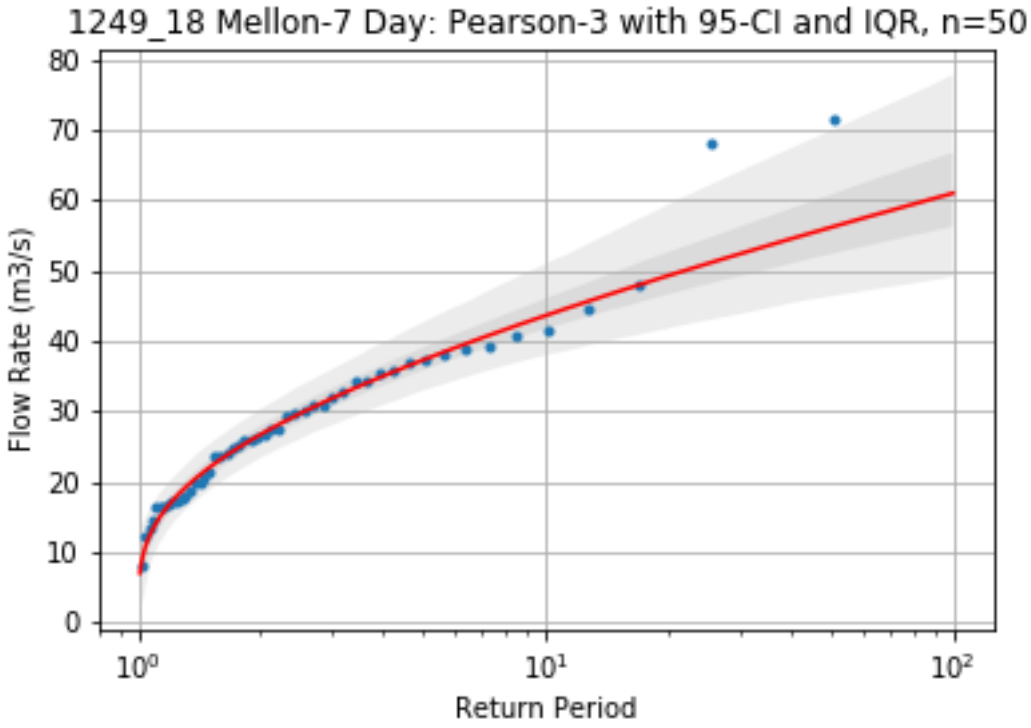

1249_18 Mellon-Peak: LP-3 with 95-CI and IQR, n=50
Flow Rate (m3/s)
Return Period
0
50
100
150
200
250
300
10^0
10^1
10^2

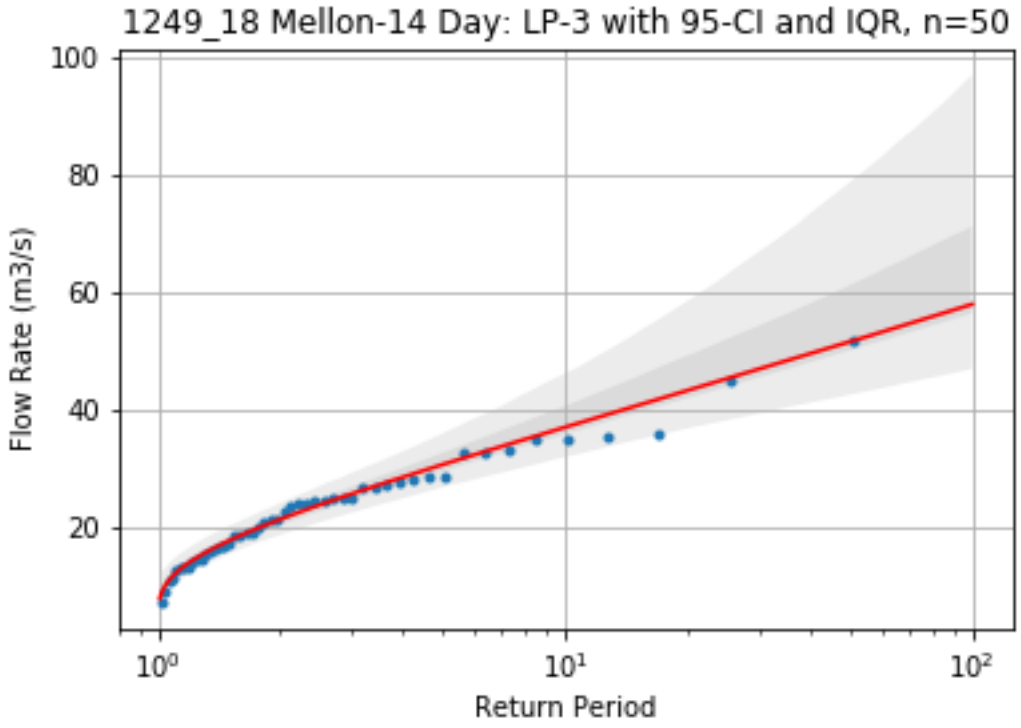

1249_18 Mellon-Peak: Pearson-3 with 95-CI and IQR, n=50
Flow Rate (m3/s)
Return Period
0
20
40
60
80
100
120
140
10^0
10^1
10^2

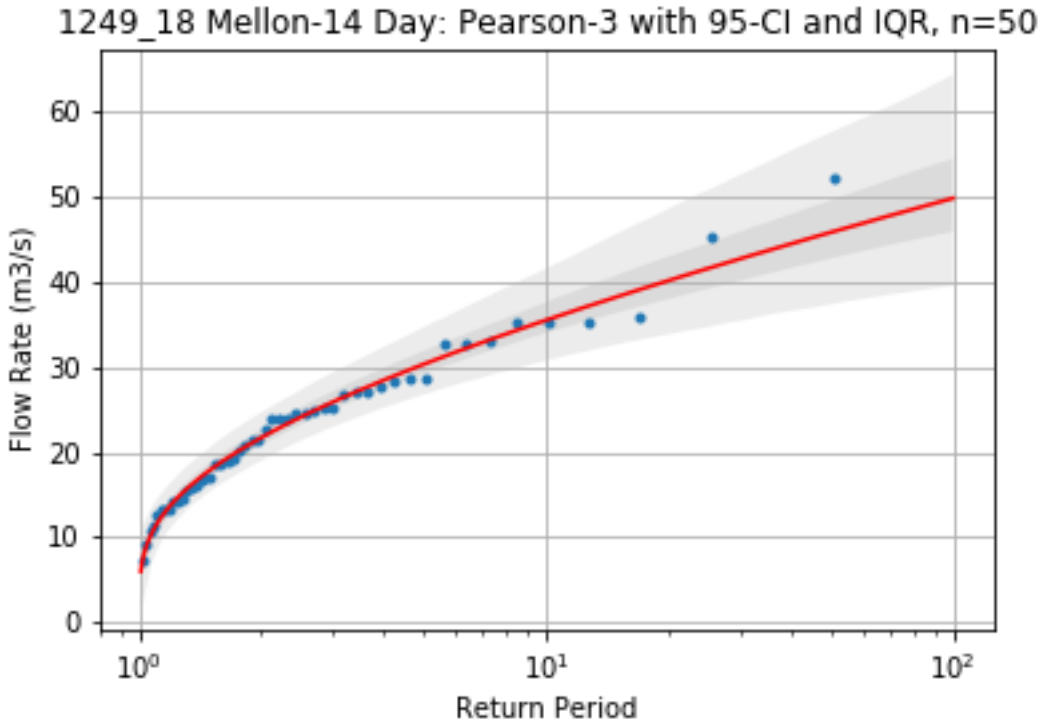

1249_18 Mellon-3 Day: LP-3 with 95-CI and IQR, n=50
Flow Rate (m3/s)
160
140
120
100
80
60
40
20
10^0
10^1
10^2
Return Period

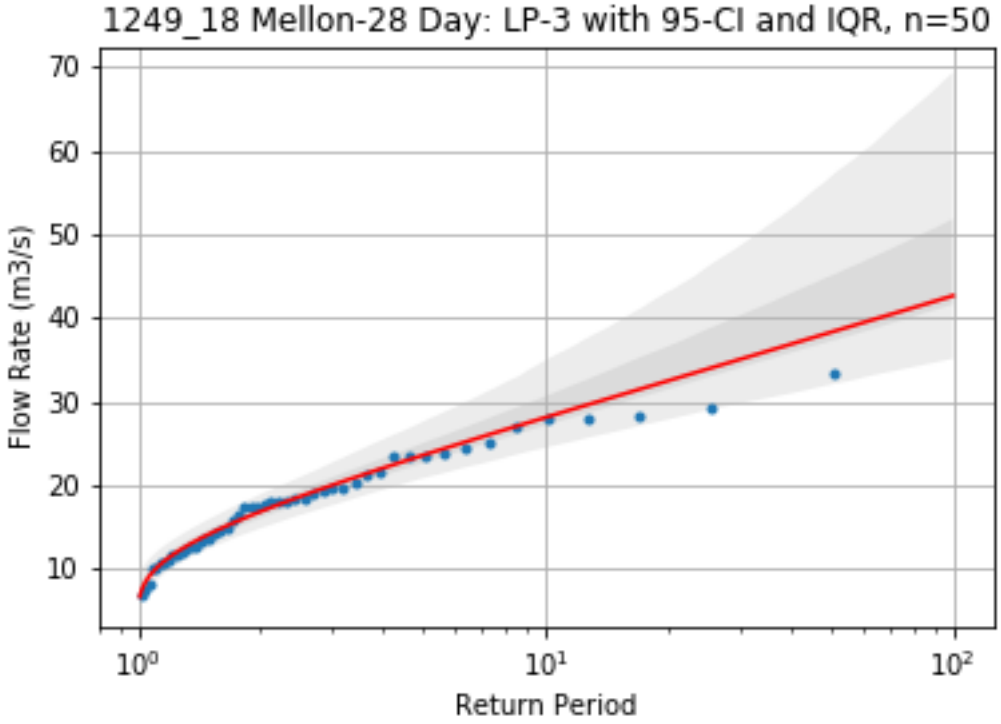

1249_18 Mellon-3 Day: Pearson-3 with 95-CI and IQR, n=50
Flow Rate (m3/s)
120
100
80
60
40
20
10^0
10^1
10^2
Return Period

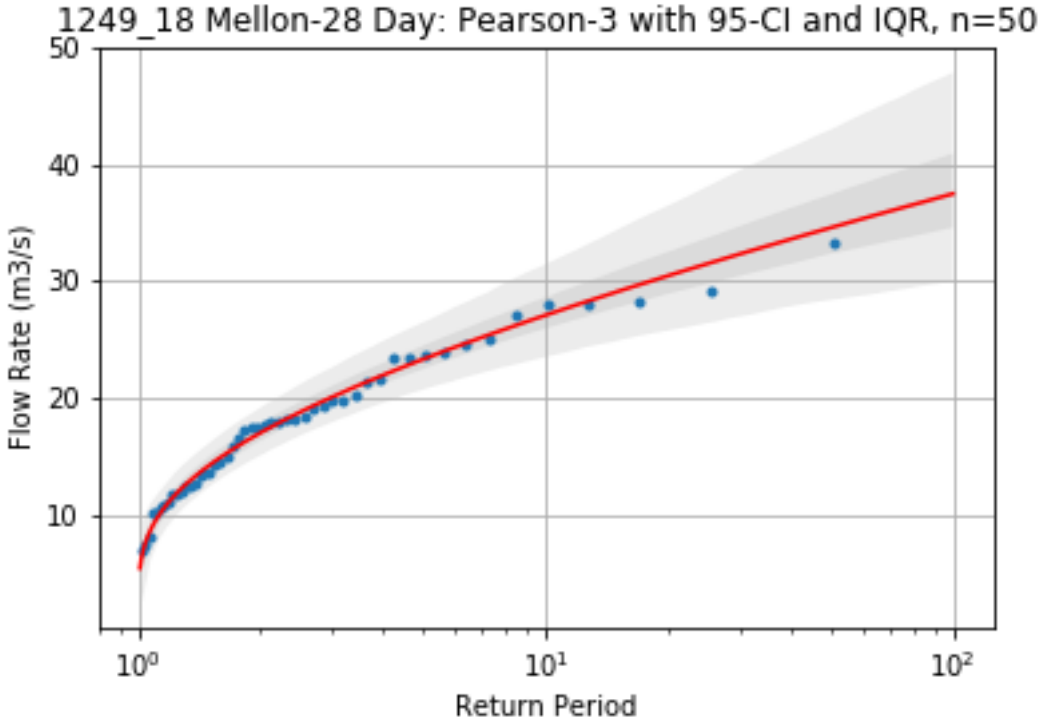

1249_18 Mellon-7 Day: LP-3 with 95-CI and IQR, n=50
Flow Rate (m3/s)
120
100
80
60
40
20
10^0
10^1
10^2
Return Period

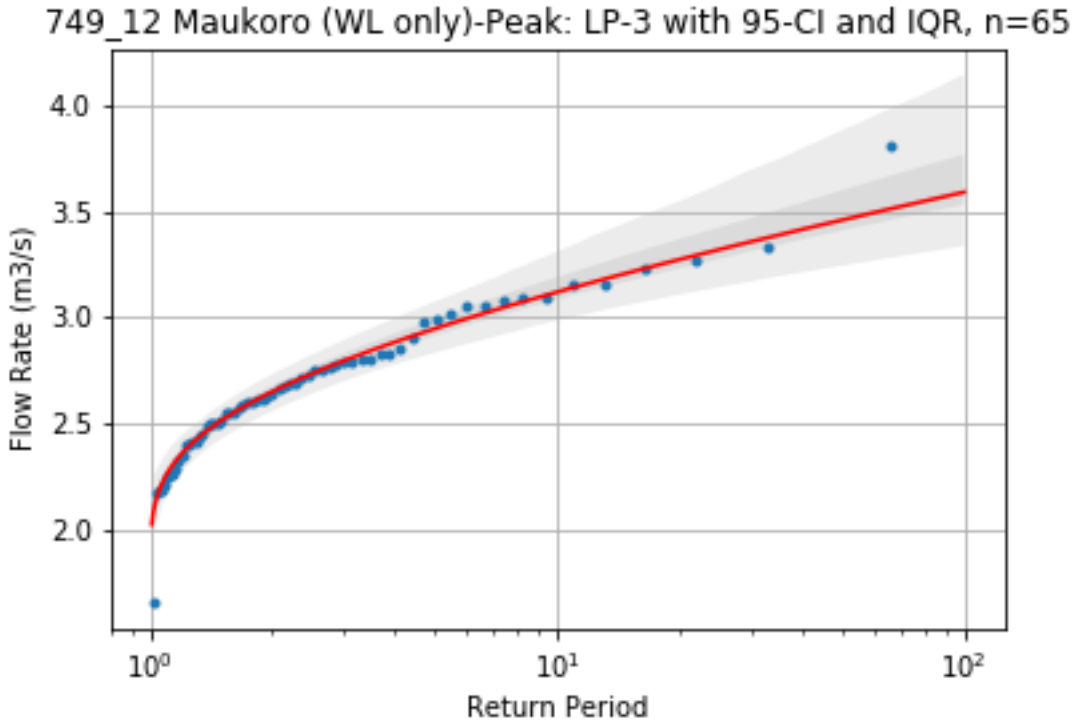

1249_18 Mellon-7 Day: Pearson-3 with 95-CI and IQR, n=50
Flow Rate (m3/s)
80
70
60
50
40
30
20
10
0
10^0
10^1
10^2
Return Period

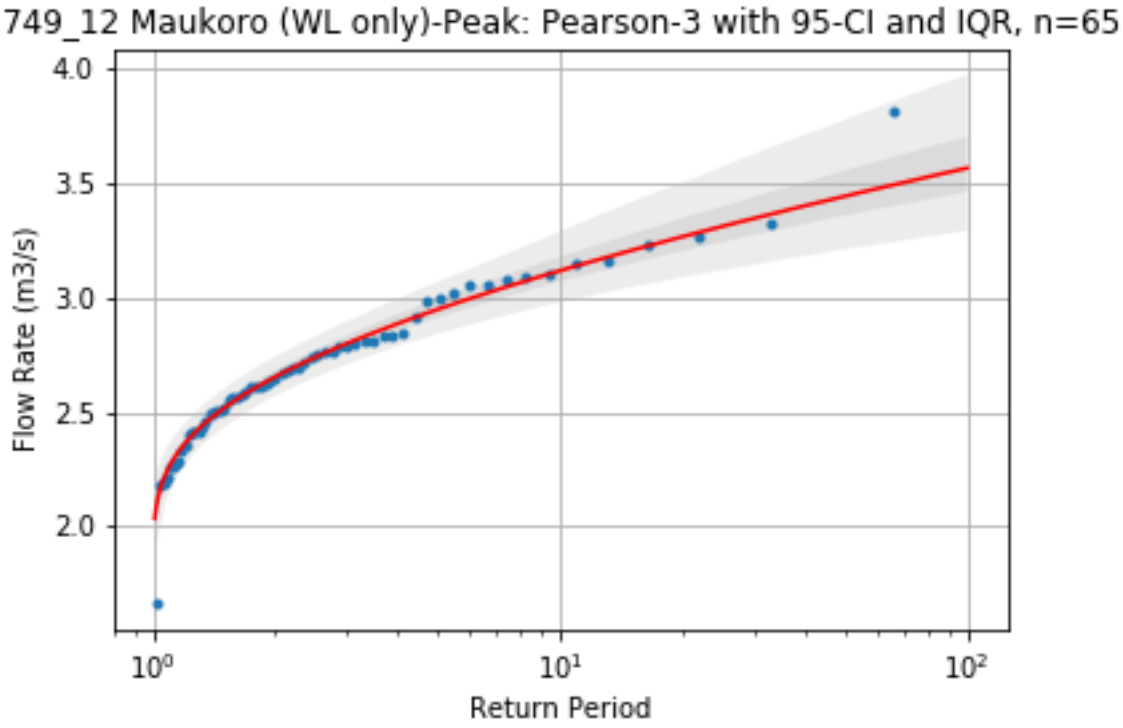

1249_18 Mellon-14 Day: LP-3 with 95-CI and IQR, n=50
Flow Rate (m3/s)
100
80
60
40
20
10^0
10^1
10^2
Return Period

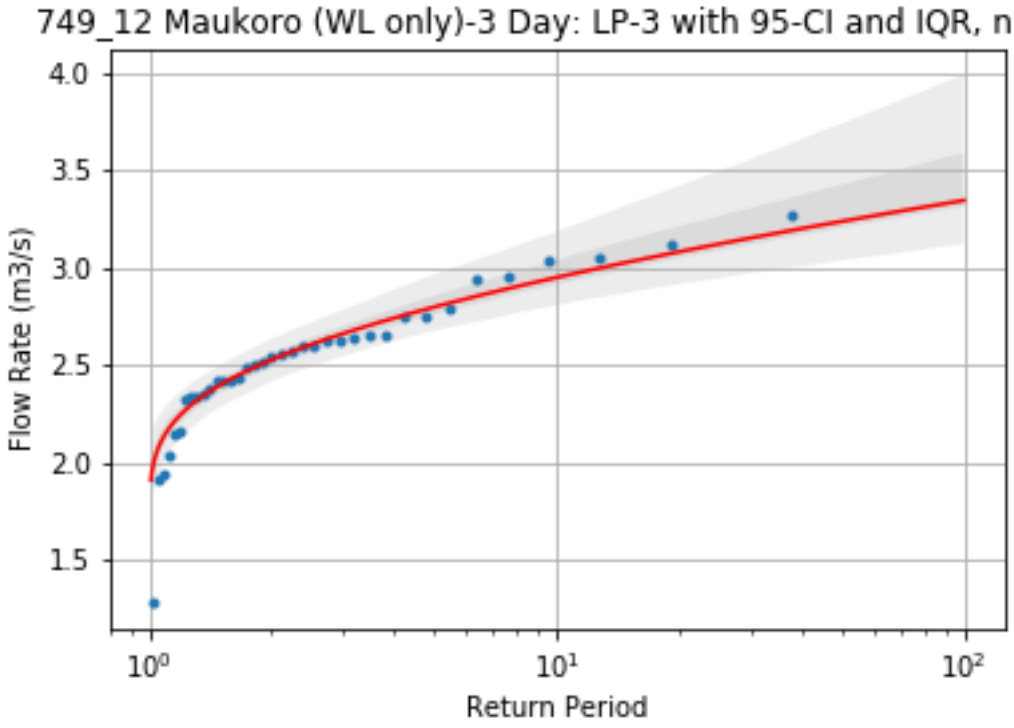

1249_18 Mellon-14 Day: Pearson-3 with 95-CI and IQR, n=50
Flow Rate (m3/s)
60
50
40
30
20
10
0
10^0
10^1
10^2
Return Period

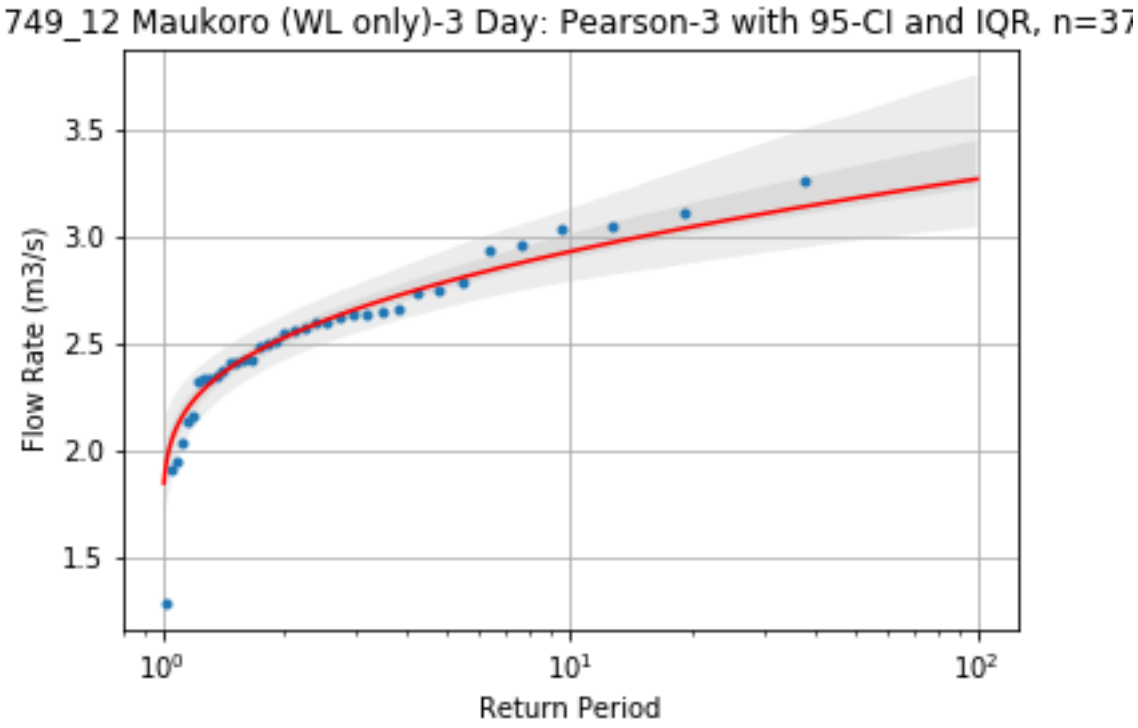

1249_18 Mellon-28 Day: LP-3 with 95-CI and IQR, n=50
Flow Rate (m3/s)
70
60
50
40
30
20
10
10^0
10^1
10^2
Return Period

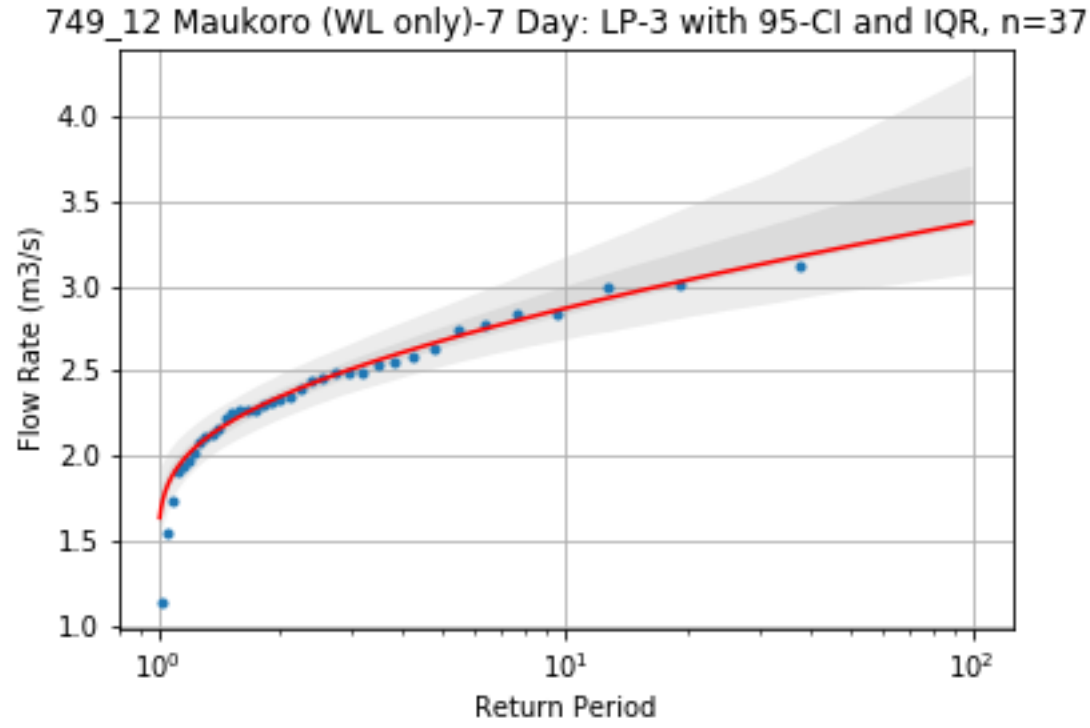

1249_18 Mellon-28 Day: Pearson-3 with 95-CI and IQR, n=50
Flow Rate (m3/s)
50
40
30
20
10
10^0
10^1
10^2
Return Period

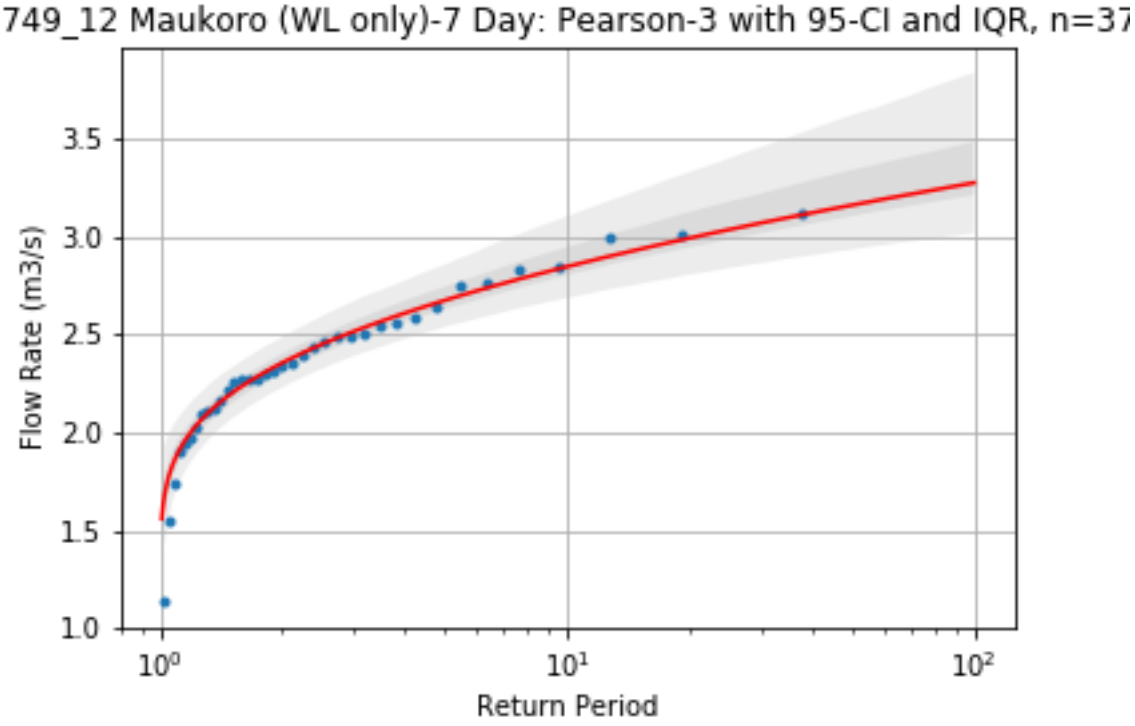

749_12 Maukoro (WL only)-Peak: LP-3 with 95-CI and IQR, n=65
Flow Rate (m3/s)
4.0
3.5
3.0
2.5
2.0
10^0
10^1
10^2
Return Period

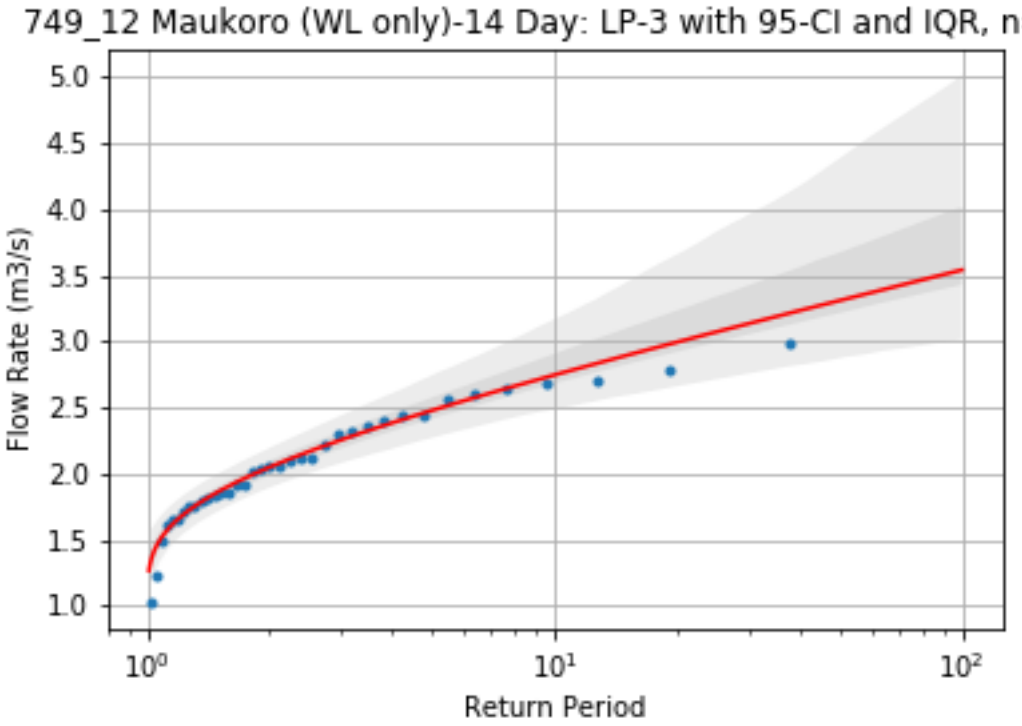

749_12 Maukoro (WL only)-Peak: Pearson-3 with 95-CI and IQR, n=65
Flow Rate (m3/s)
4.0
3.5
3.0
2.5
2.0
10^0
10^1
10^2
Return Period

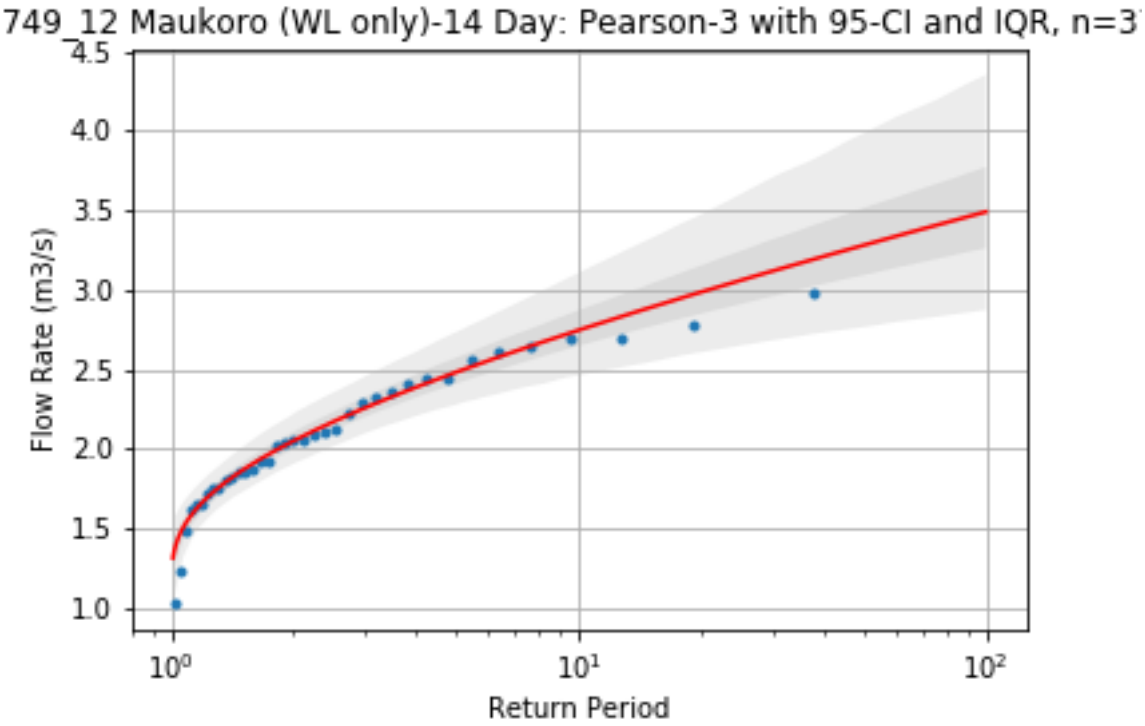

749_12 Maukoro (WL only)-3 Day: LP-3 with 95-CI and IQR, n=37
Flow Rate (m3/s)
4.0
3.5
3.0
2.5
2.0
1.5
10^0
10^1
10^2
Return Period

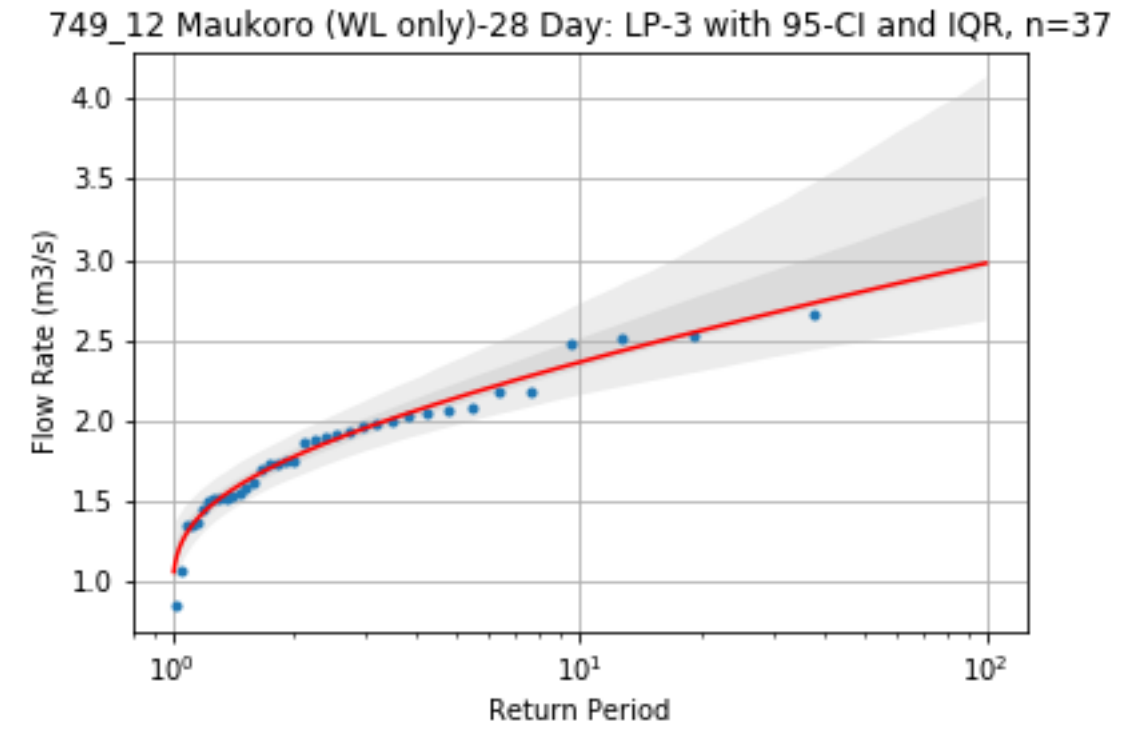

749_12 Maukoro (WL only)-3 Day: Pearson-3 with 95-CI and IQR, n=37
Flow Rate (m3/s)
3.5
3.0
2.5
2.0
1.5
10^0
10^1
10^2
Return Period

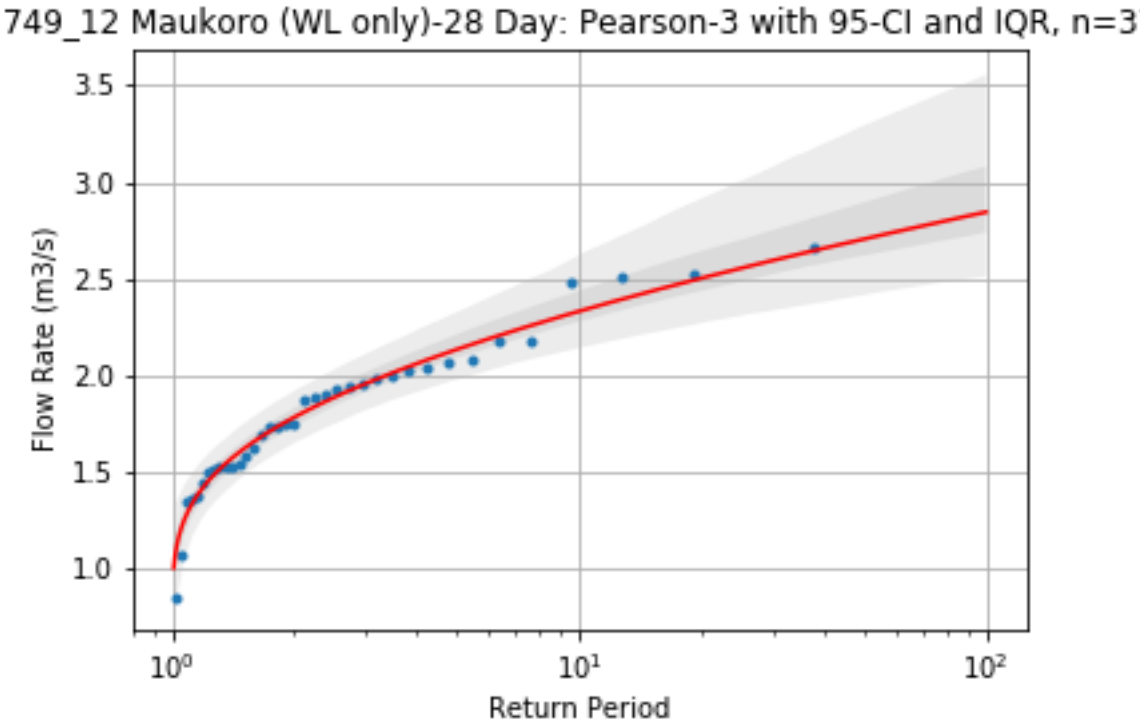

749_12 Maukoro (WL only)-7 Day: LP-3 with 95-CI and IQR, n=37
Flow Rate (m3/s)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
10^0
10^1
10^2
Return Period

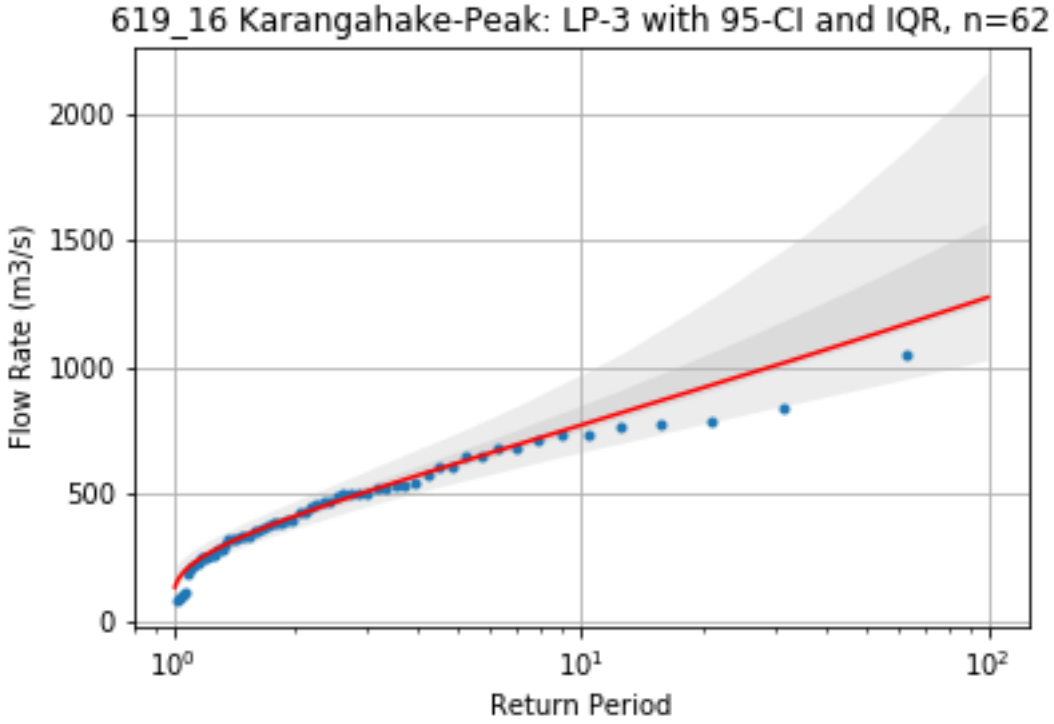

749_12 Maukoro (WL only)-7 Day: Pearson-3 with 95-CI and IQR, n=37
Flow Rate (m3/s)
3.5
3.0
2.5
2.0
1.5
1.0
10^0
10^1
10^2
Return Period

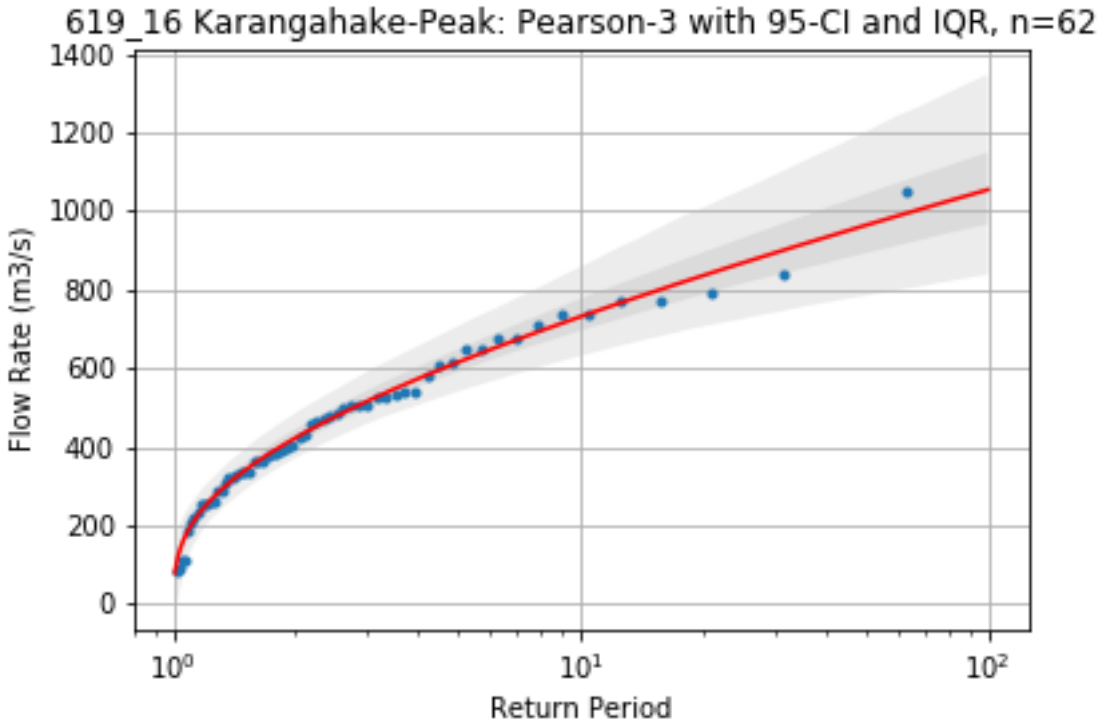

749_12 Maukoro (WL only)-14 Day: LP-3 with 95-CI and IQR, n=37
Flow Rate (m3/s)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
10^0
10^1
10^2
Return Period

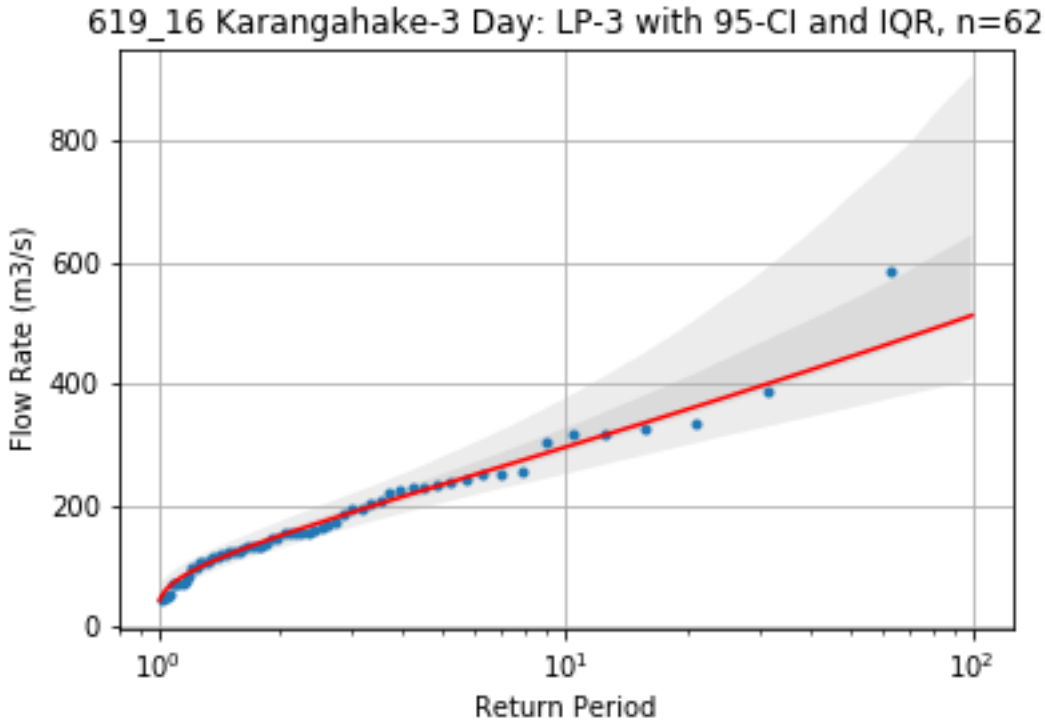

749_12 Maukoro (WL only)-14 Day: Pearson-3 with 95-CI and IQR, n=3
Flow Rate (m3/s)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
10^0
10^1
10^2
Return Period

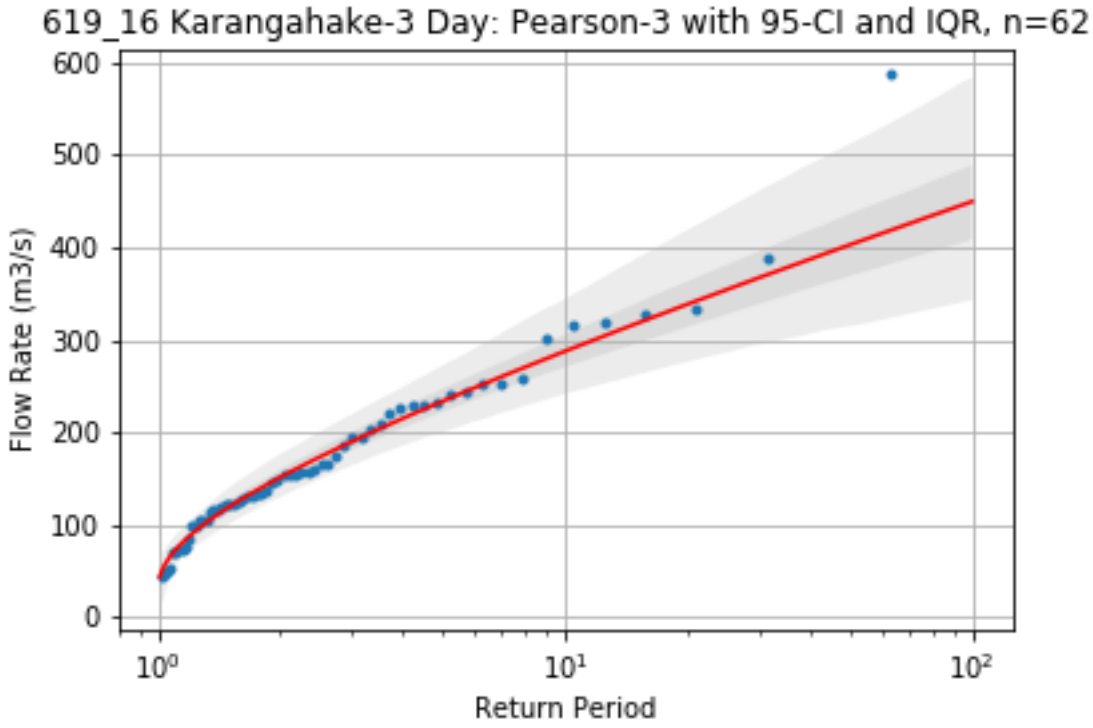

749_12 Maukoro (WL only)-28 Day: LP-3 with 95-CI and IQR, n=37
Flow Rate (m3/s)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
10^0
10^1
10^2
Return Period

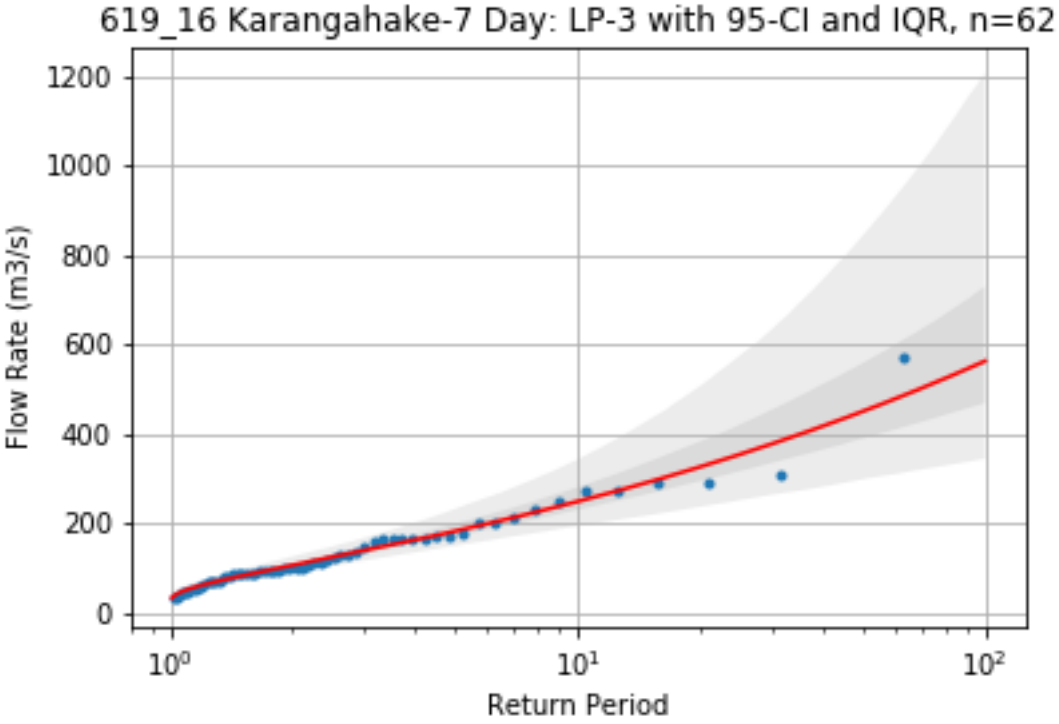

749_12 Maukoro (WL only)-28 Day: Pearson-3 with 95-CI and IQR, n=3
Flow Rate (m3/s)
3.5
3.0
2.5
2.0
1.5
1.0
10^0
10^1
10^2
Return Period

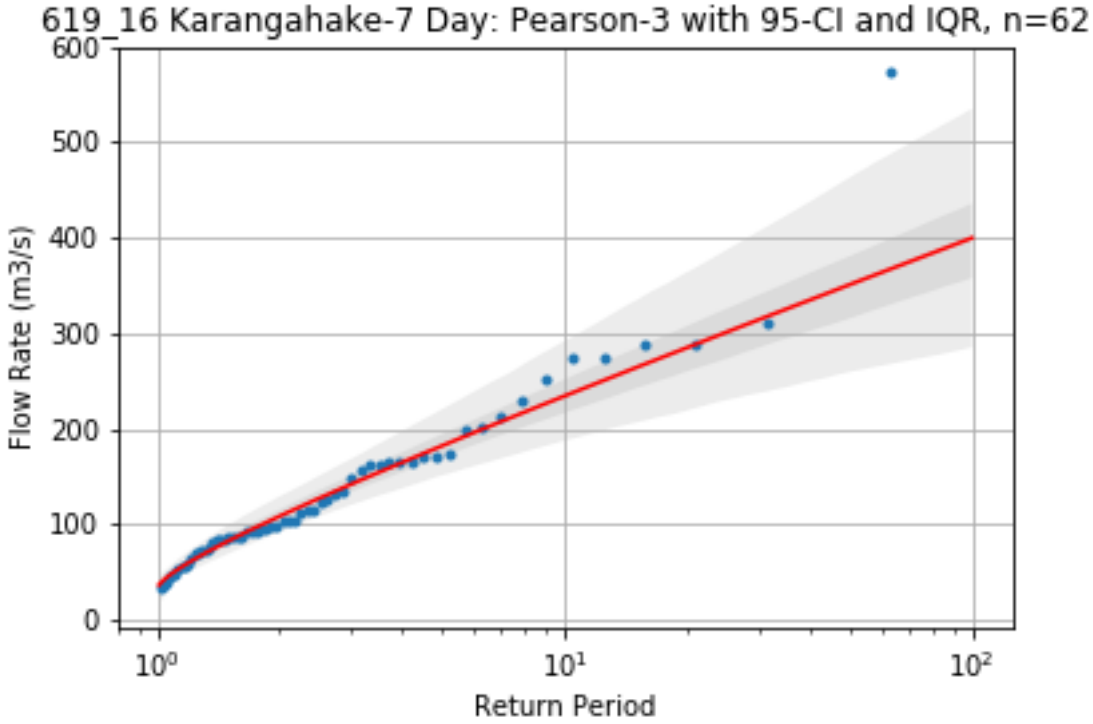

619_16 Karangahake-Peak: LP-3 with 95-CI and IQR, n=62
Flow Rate (m3/s)
2000
1500
1000
500
0
10^0
10^1
10^2
Return Period

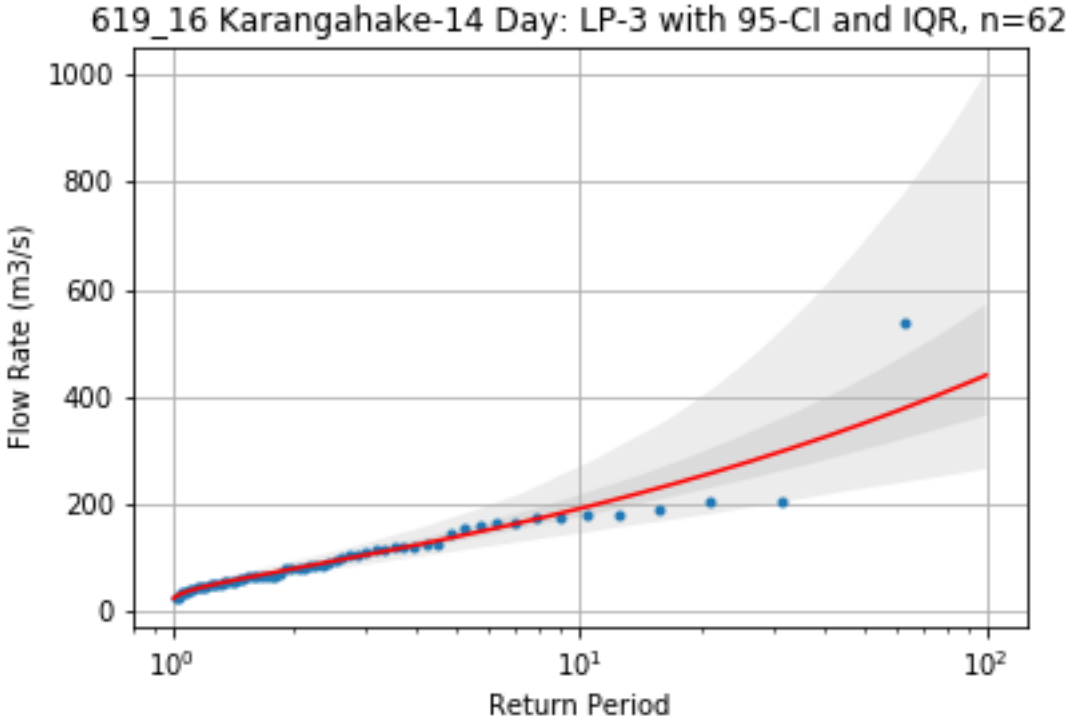

619_16 Karangahake-Peak: Pearson-3 with 95-CI and IQR, n=62
Flow Rate (m3/s)
1400
1200
1000
800
600
400
200
0
10^0
10^1
10^2
Return Period

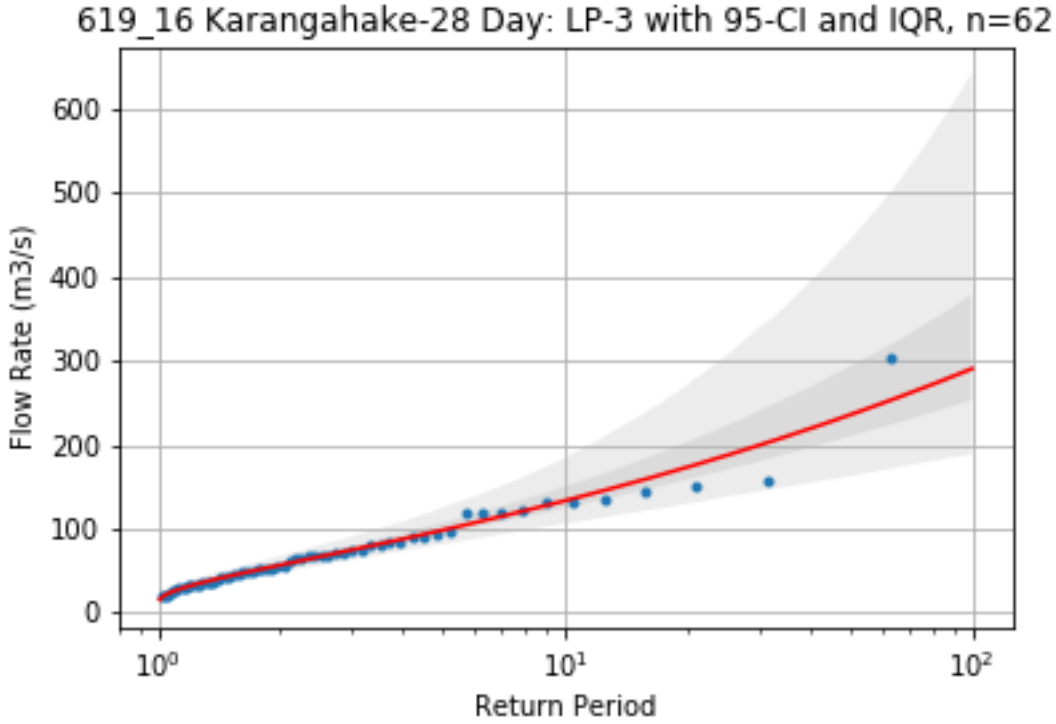

619_16 Karangahake-3 Day: LP-3 with 95-CI and IQR, n=62
Flow Rate (m3/s)
0
200
400
600
800
10^0
10^1
10^2
Return Period

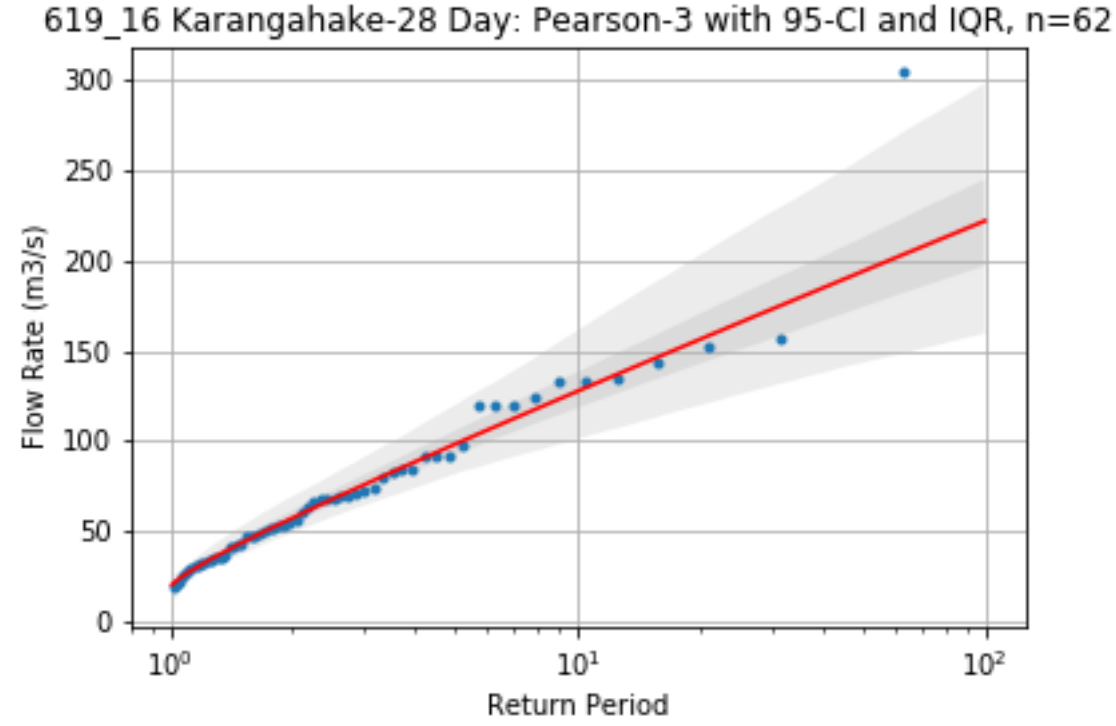

619_16 Karangahake-3 Day: Pearson-3 with 95-CI and IQR, n=62
Flow Rate (m3/s)
0
100
200
300
400
500
600
10^0
10^1
10^2
Return Period

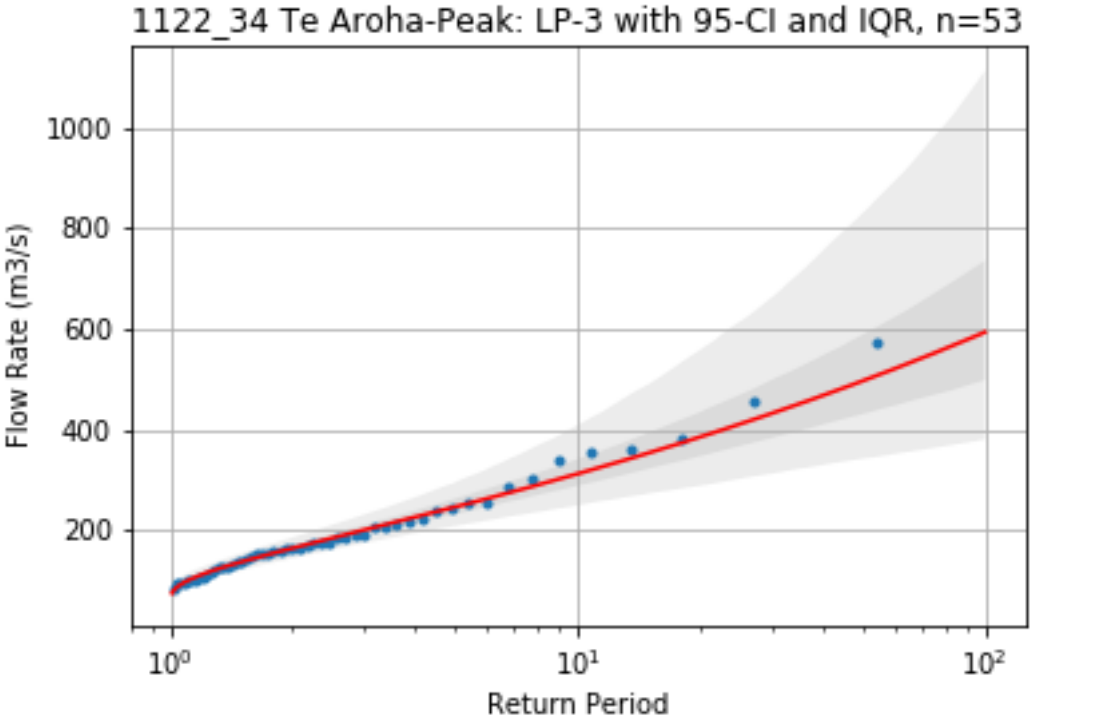

619_16 Karangahake-7 Day: LP-3 with 95-CI and IQR, n=62
Flow Rate (m3/s)
Return Period
0
200
400
600
800
1000
1200
10^0
10^1
10^2

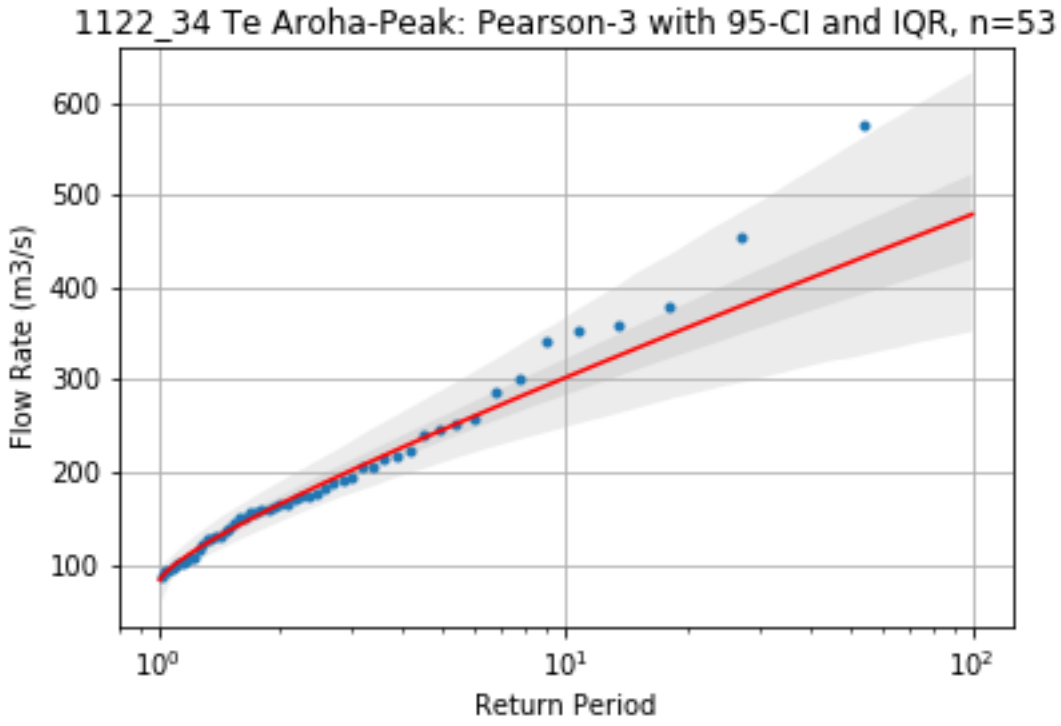

619_16 Karangahake-7 Day: Pearson-3 with 95-CI and IQR, n=62
Flow Rate (m3/s)
Return Period
0
100
200
300
400
500
600
10^0
10^1
10^2

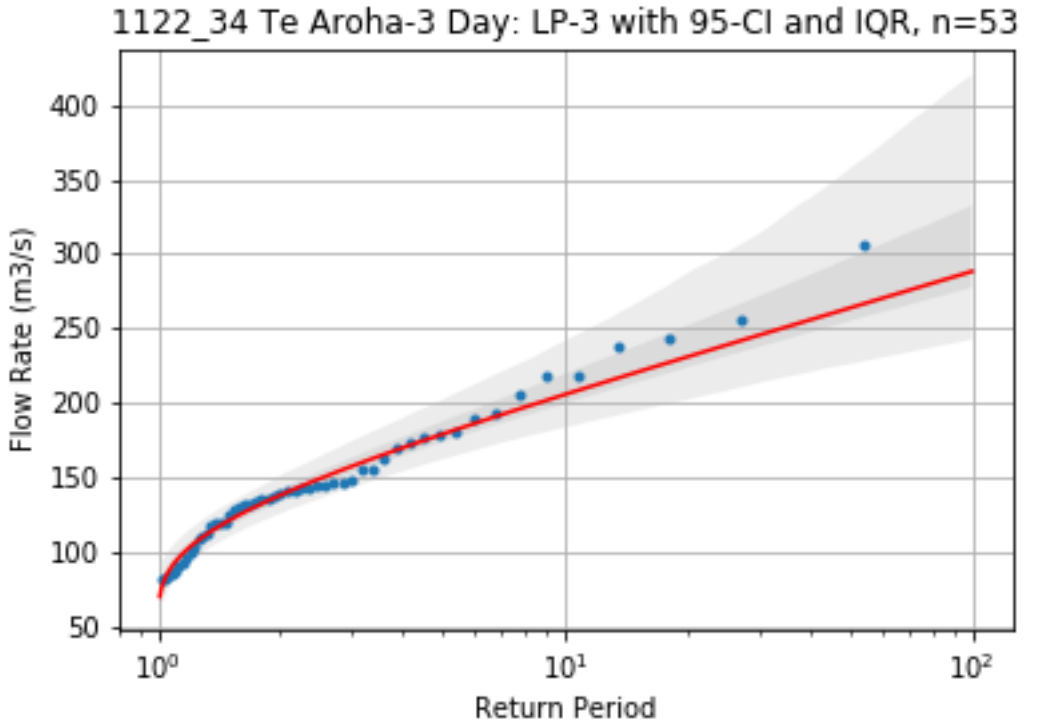

619_16 Karangahake-14 Day: LP-3 with 95-CI and IQR, n=62
Flow Rate (m3/s)
1000
800
600
400
200
0
10^0
10^1
10^2
Return Period

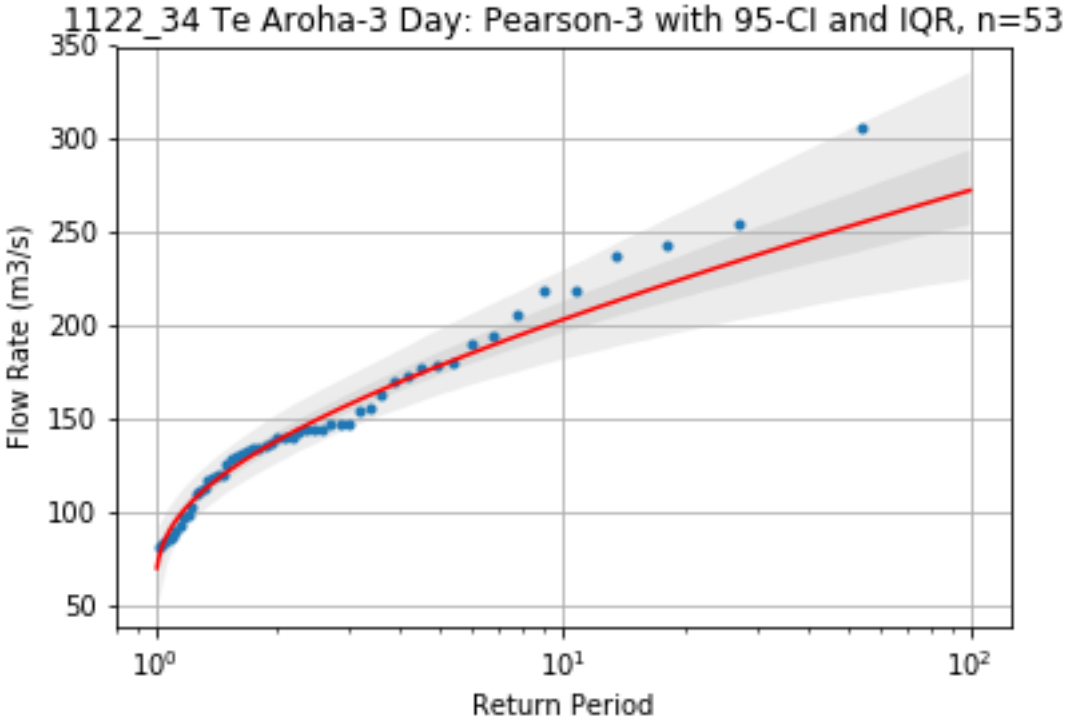

619_16 Karangahake-28 Day: LP-3 with 95-CI and IQR, n=62
Flow Rate (m3/s)
600
500
400
300
200
100
0
10^0
10^1
10^2
Return Period

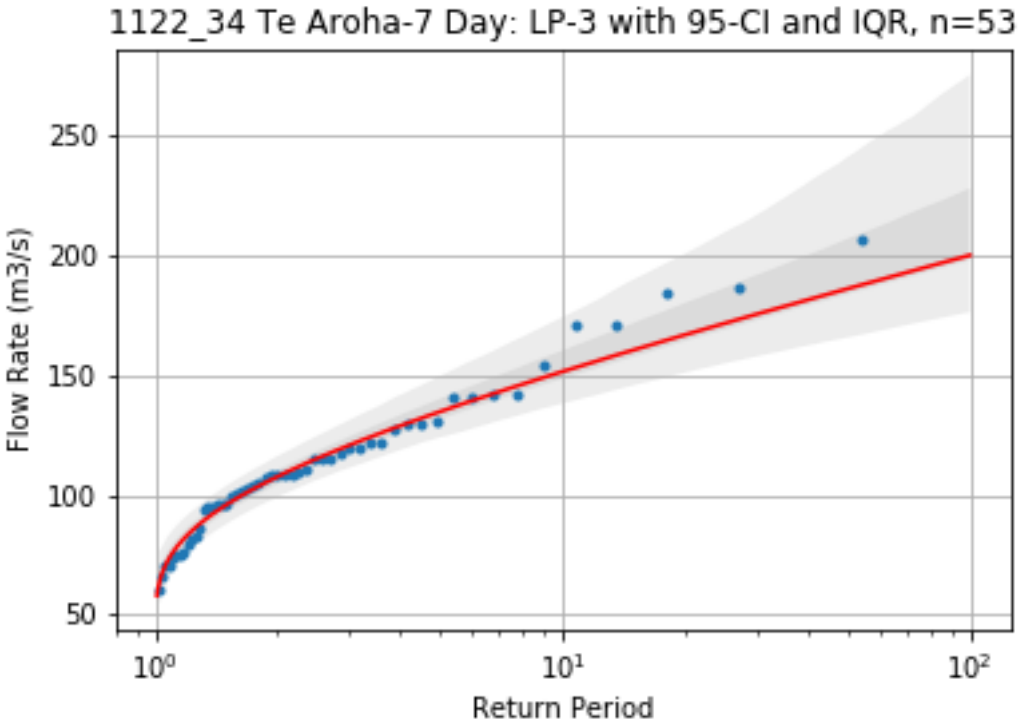

619_16 Karangahake-28 Day: Pearson-3 with 95-CI and IQR, n=62
Flow Rate (m3/s)
300
250
200
150
100
50
0
10^0
10^1
10^2
Return Period

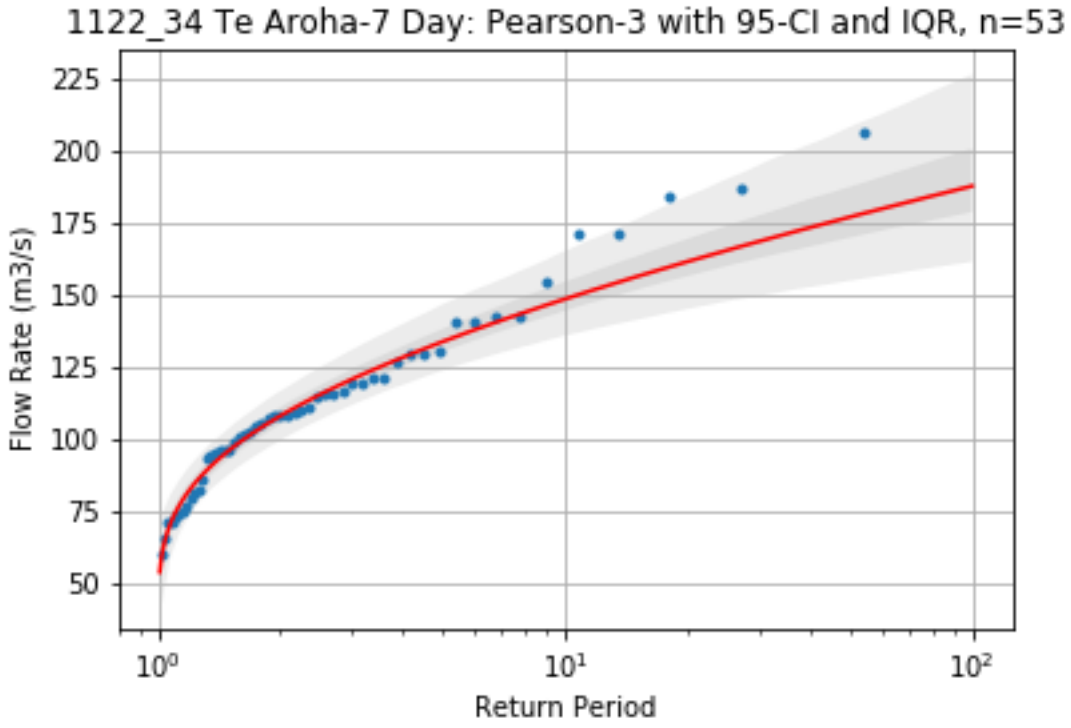

1122_34 Te Aroha-Peak: LP-3 with 95-CI and IQR, n=53
Flow Rate (m3/s)
1000
800
600
400
200
10^0
10^1
10^2
Return Period

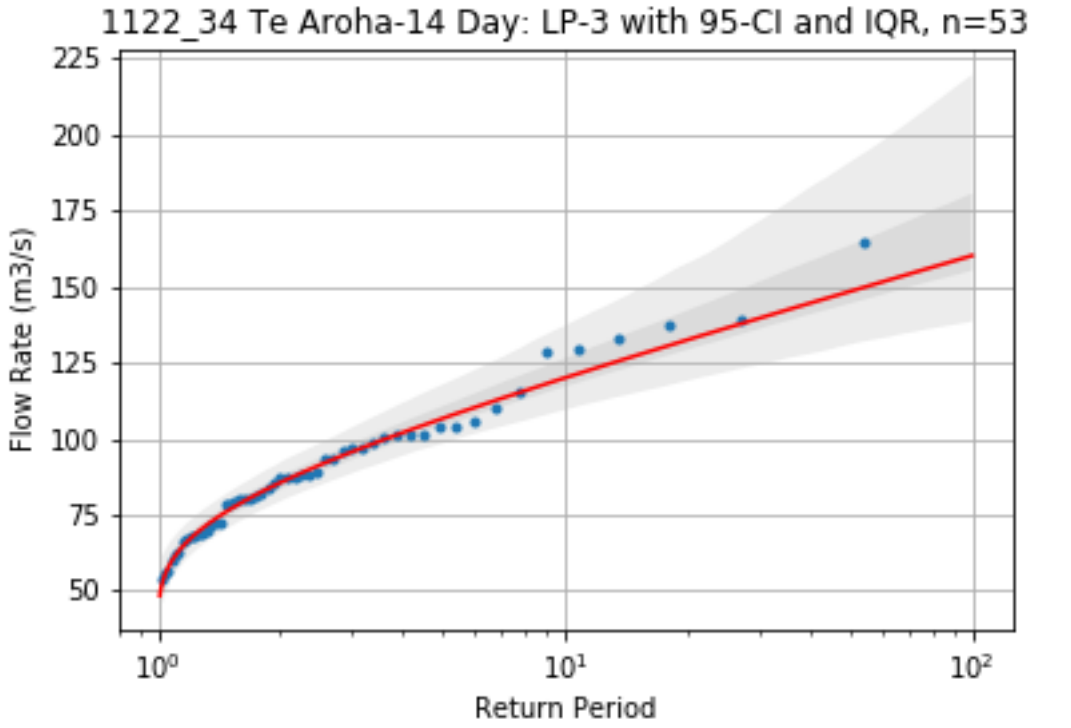

1122_34 Te Aroha-Peak: Pearson-3 with 95-CI and IQR, n=53
Flow Rate (m3/s)
600
500
400
300
200
100
10^0
10^1
10^2
Return Period

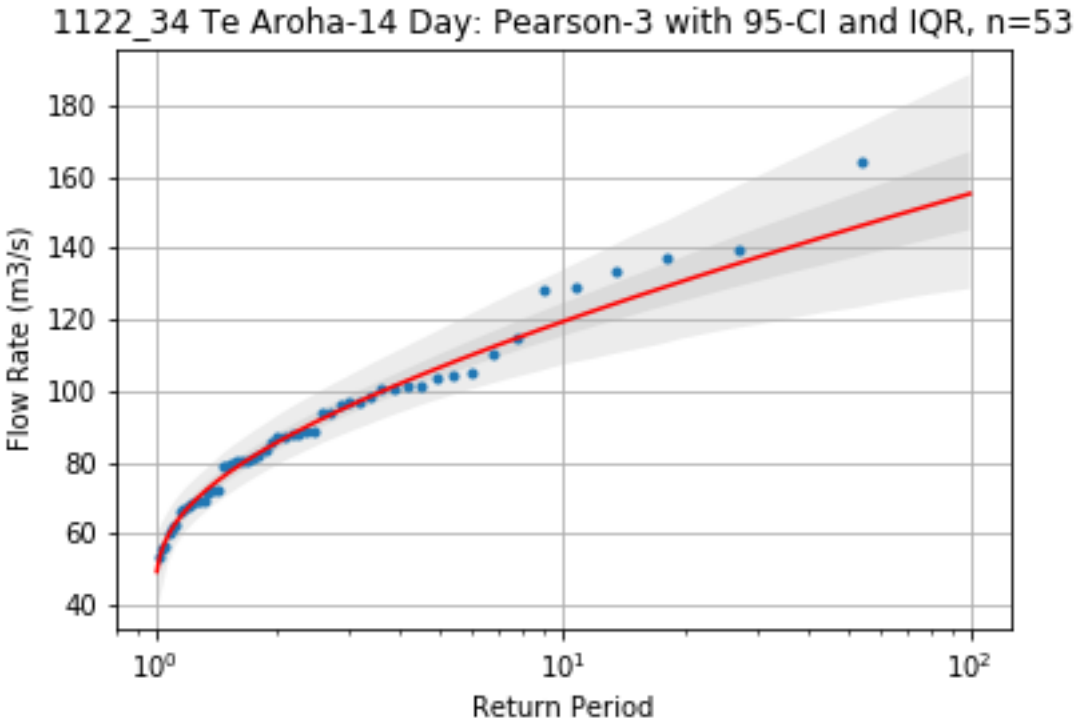

1122_34 Te Aroha-3 Day: LP-3 with 95-CI and IQR, n=53
Flow Rate (m3/s)
400
350
300
250
200
150
100
50
10^0
10^1
10^2
Return Period

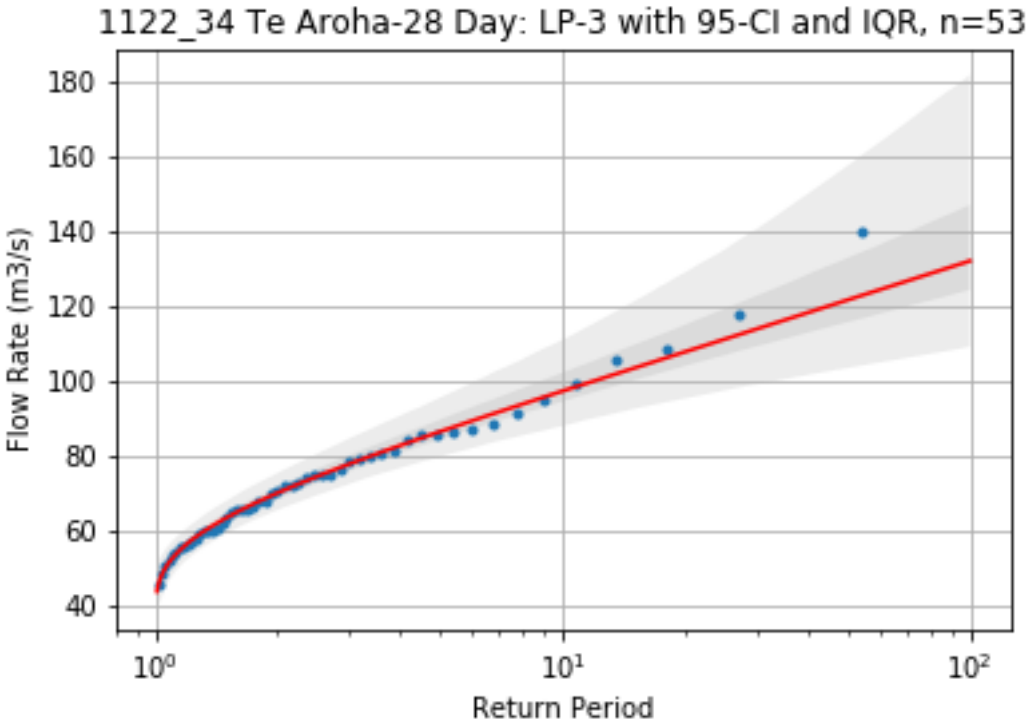

1122_34 Te Aroha-3 Day: Pearson-3 with 95-CI and IQR, n=53
Flow Rate (m3/s)
350
300
250
200
150
100
50
10^0
10^1
10^2
Return Period

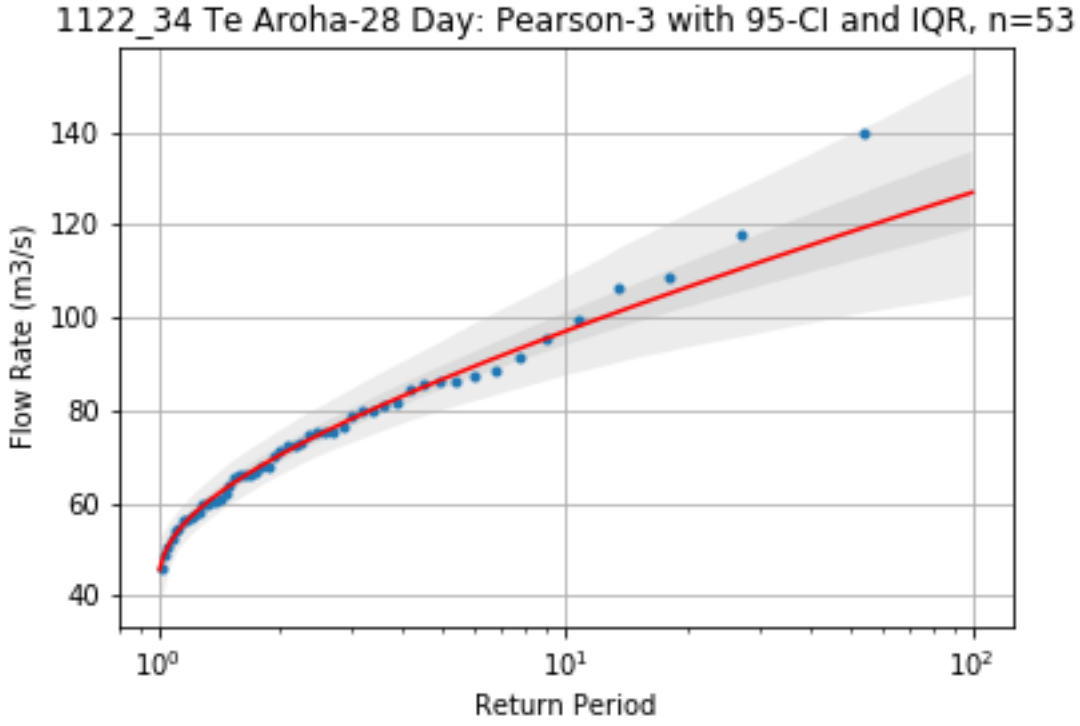

1122_34 Te Aroha-7 Day: LP-3 with 95-CI and IQR, n=53
Flow Rate (m3/s)
250
200
150
100
50
10^0
10^1
10^2
Return Period

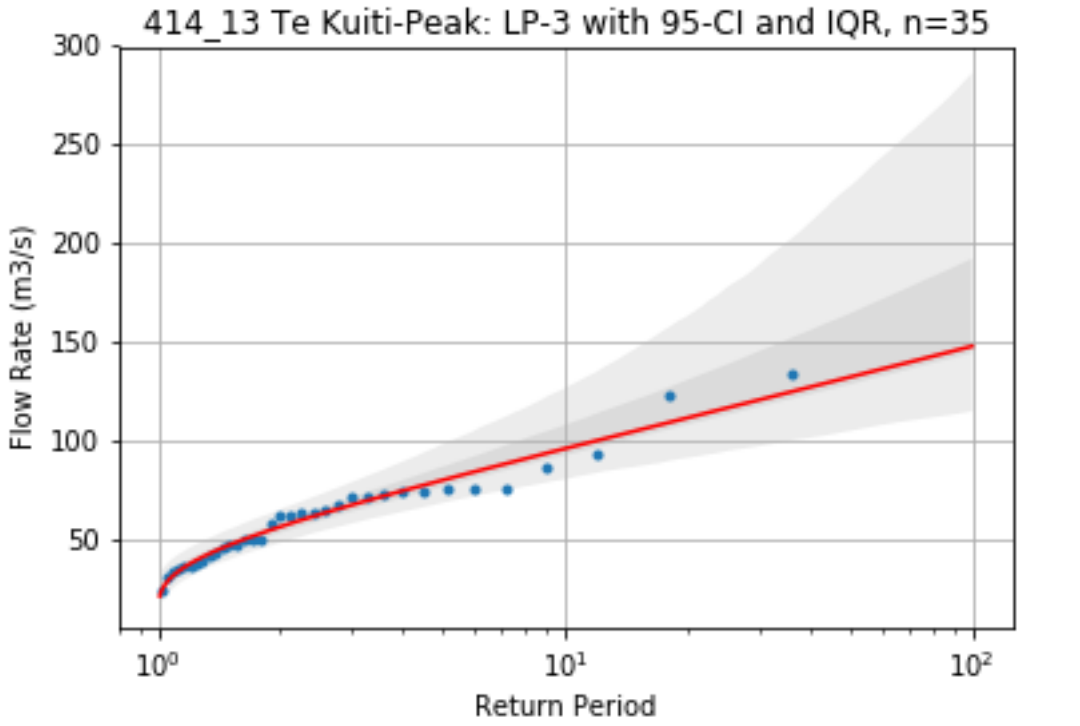

1122_34 Te Aroha-7 Day: Pearson-3 with 95-CI and IQR, n=53
Flow Rate (m3/s)
225
200
175
150
125
100
75
50
10^0
10^1
10^2
Return Period

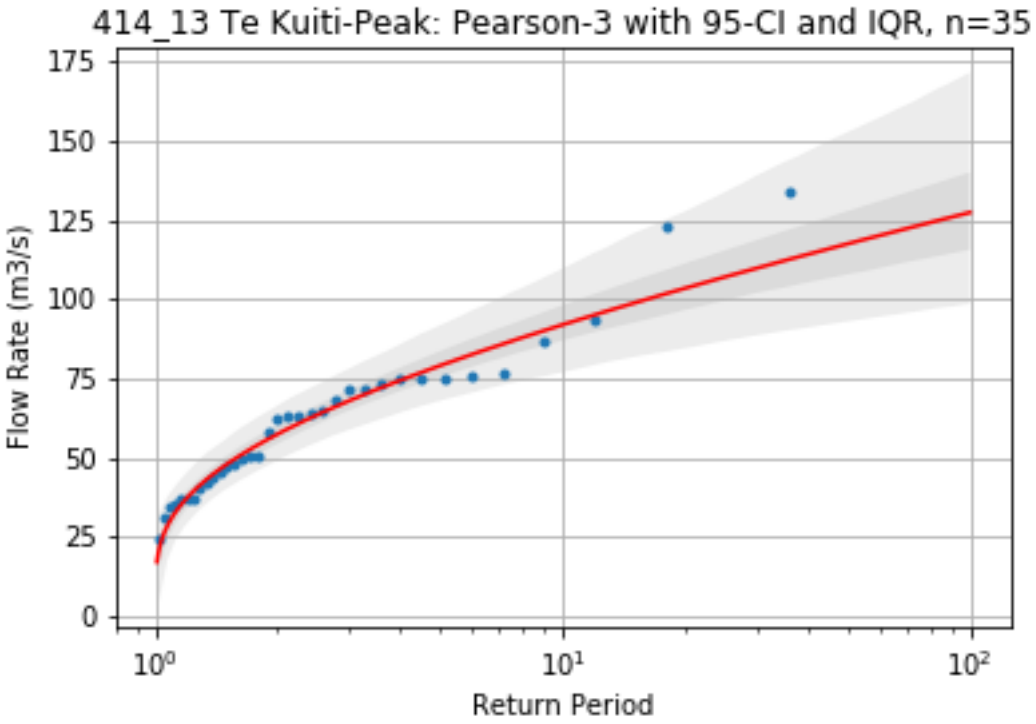

1122_34 Te Aroha-14 Day: LP-3 with 95-CI and IQR, n=53
Flow Rate (m3/s)
225
200
175
150
125
100
75
50
10^0
10^1
10^2
Return Period

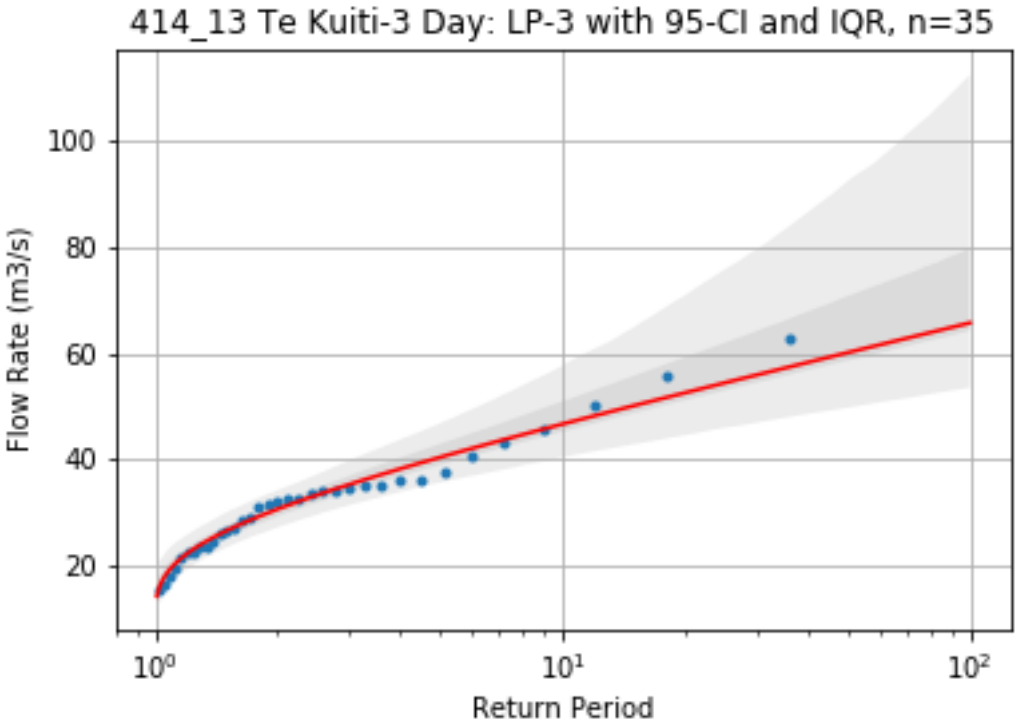

1122_34 Te Aroha-14 Day: Pearson-3 with 95-CI and IQR, n=53
Flow Rate (m3/s)
180
160
140
120
100
80
60
40
10^0
10^1
10^2
Return Period

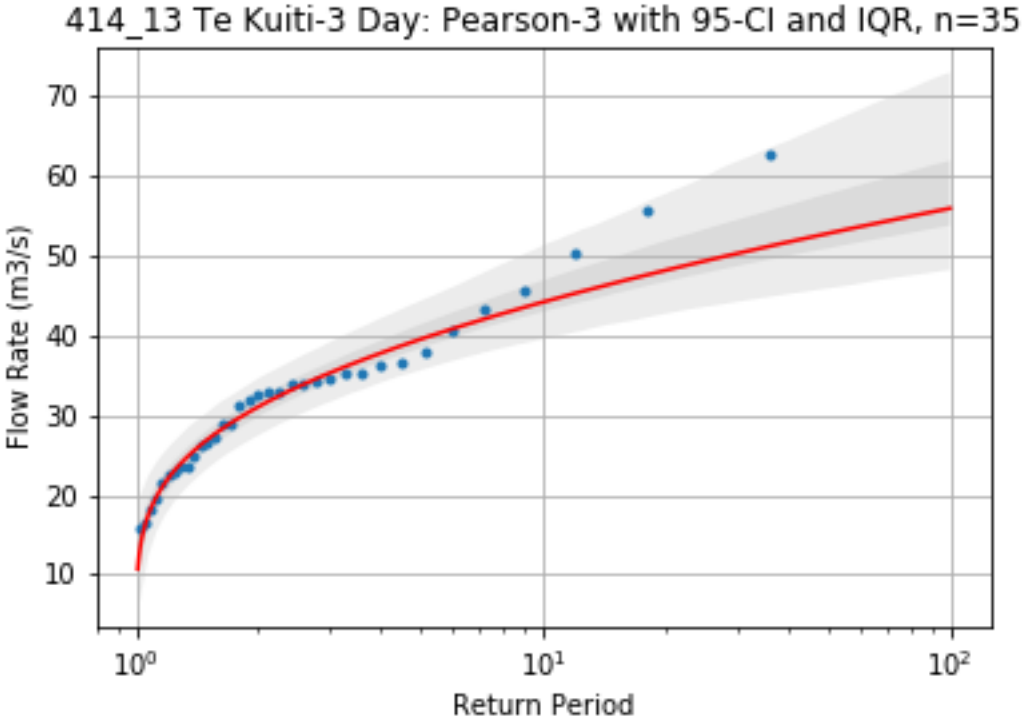

1122_34 Te Aroha-28 Day: LP-3 with 95-CI and IQR, n=53
Flow Rate (m3/s)
180
160
140
120
100
80
60
40
10^0
10^1
10^2
Return Period

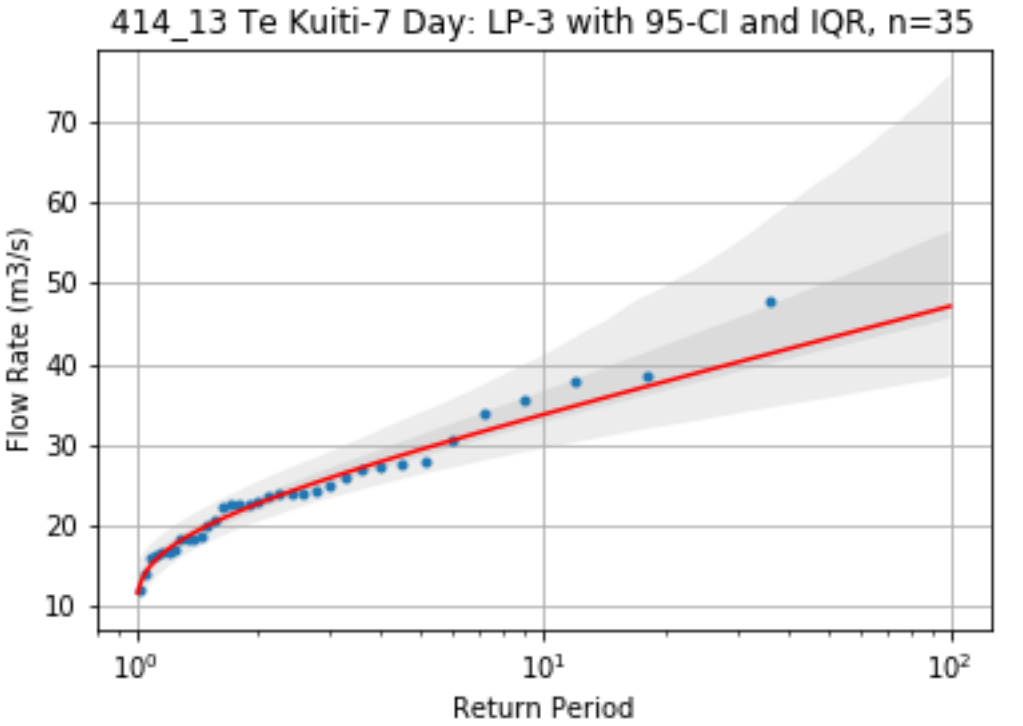

1122_34 Te Aroha-28 Day: Pearson-3 with 95-CI and IQR, n=53
Flow Rate (m3/s)
140
120
100
80
60
40
10^0
10^1
10^2
Return Period

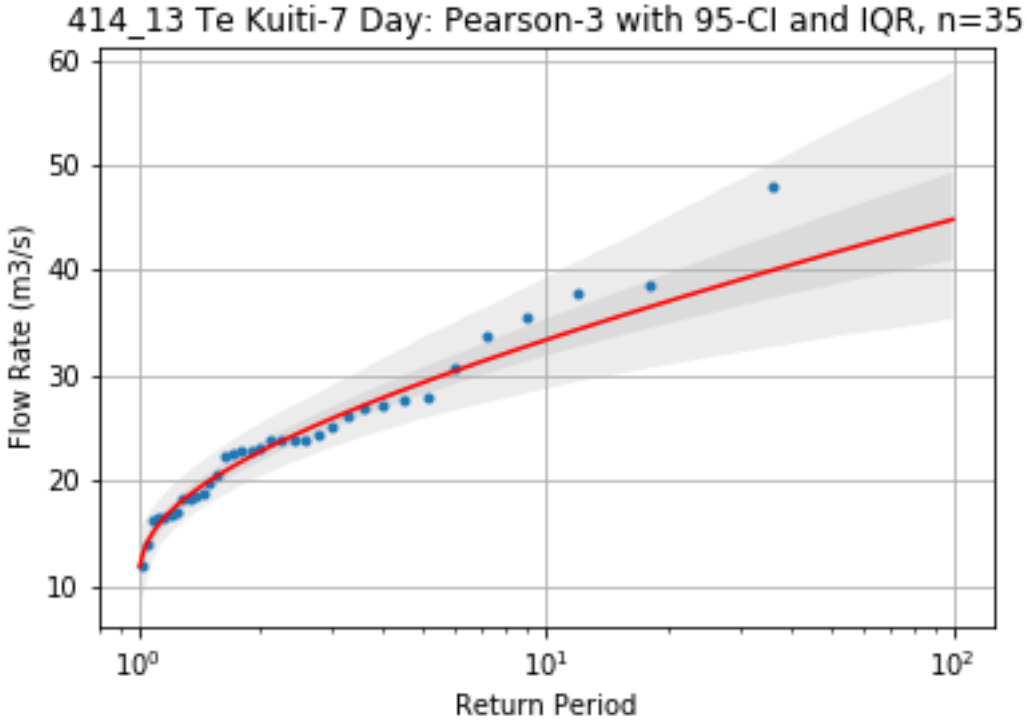

414_13 Te Kuiti-Peak: LP-3 with 95-CI and IQR, n=35
Flow Rate (m3/s)
300
250
200
150
100
50
10^0
10^1
10^2
Return Period

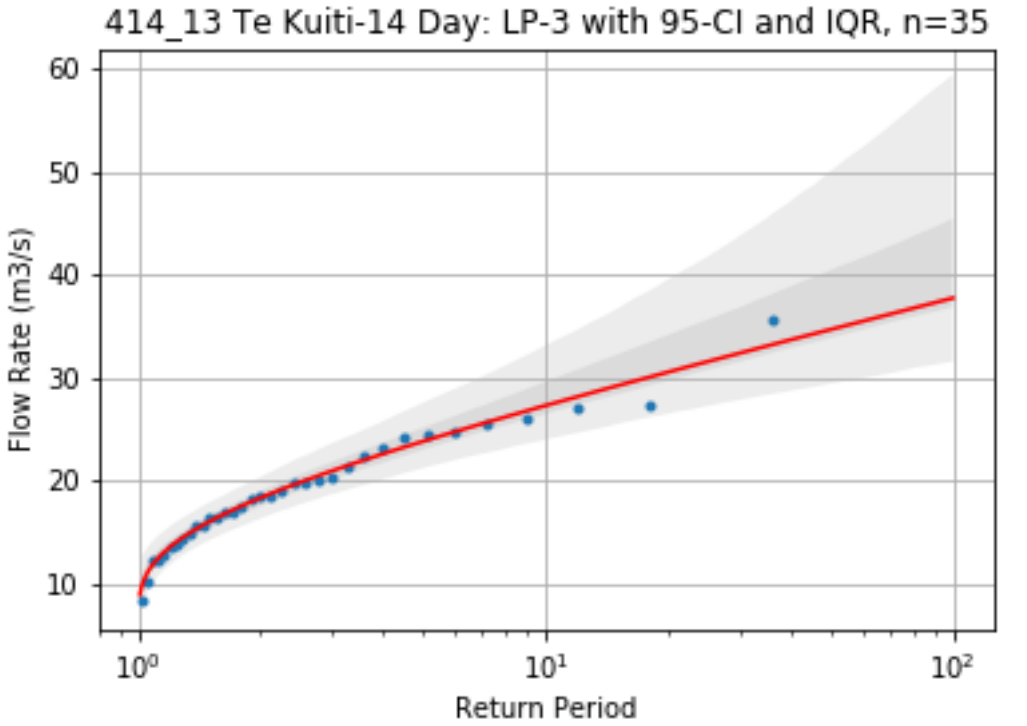

414_13 Te Kuiti-Peak: Pearson-3 with 95-CI and IQR, n=35
Flow Rate (m3/s)
175
150
125
100
75
50
25
0
10^0
10^1
10^2
Return Period

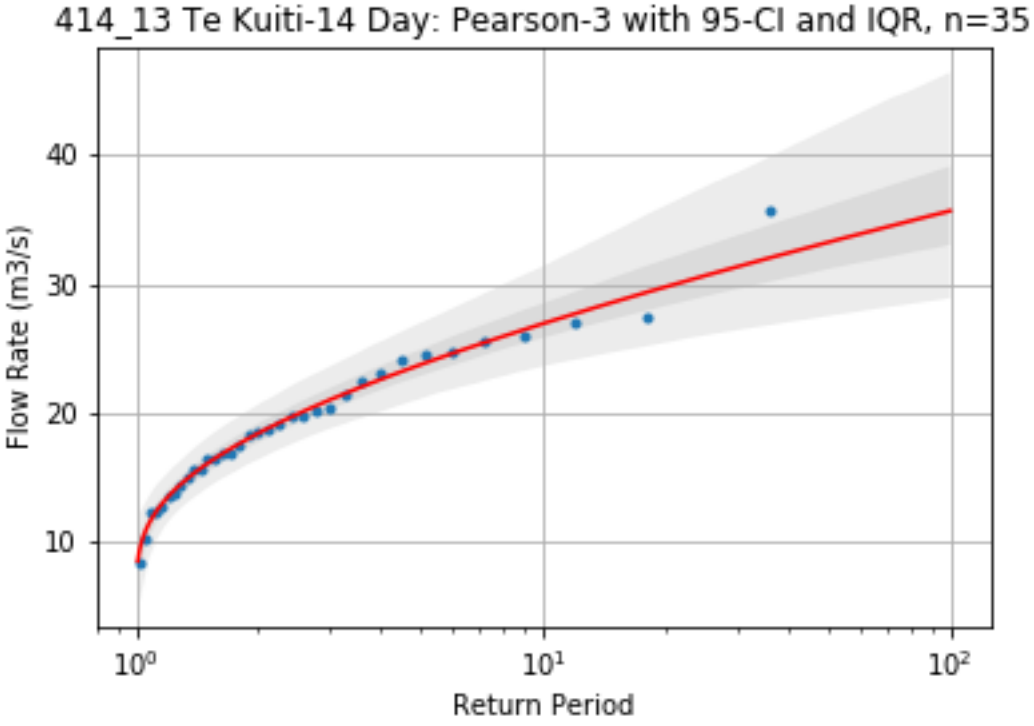

414_13 Te Kuiti-3 Day: LP-3 with 95-CI and IQR, n=35
Flow Rate (m3/s)
100
80
60
40
20
10^0
10^1
10^2
Return Period

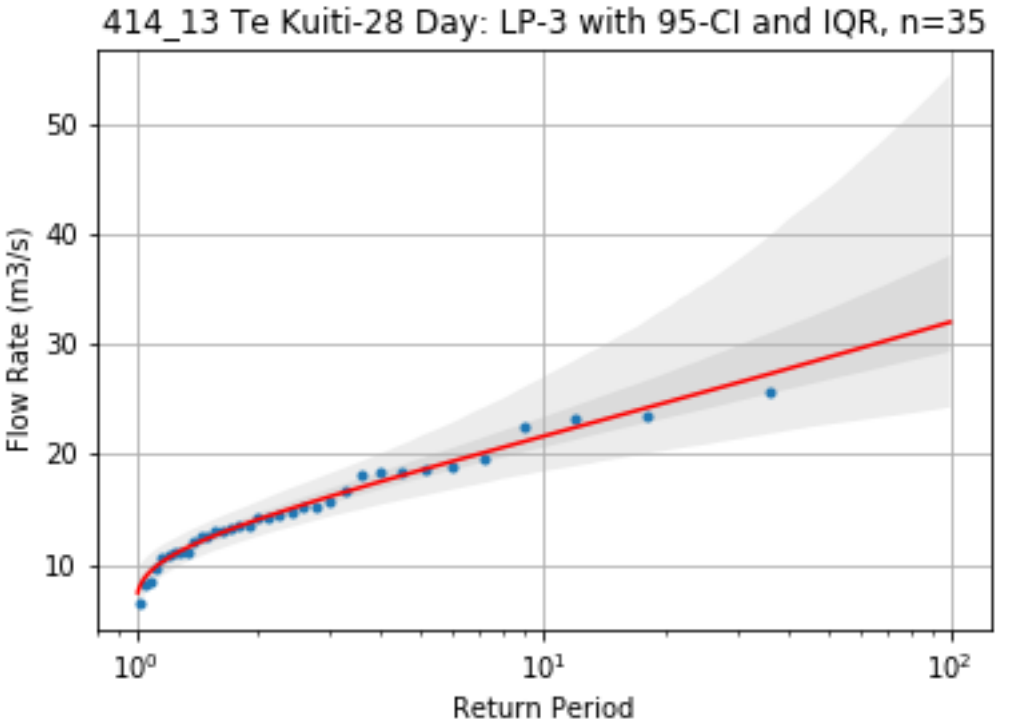

414_13 Te Kuiti-3 Day: Pearson-3 with 95-CI and IQR, n=35
Flow Rate (m3/s)
70
60
50
40
30
20
10
10^0
10^1
10^2
Return Period

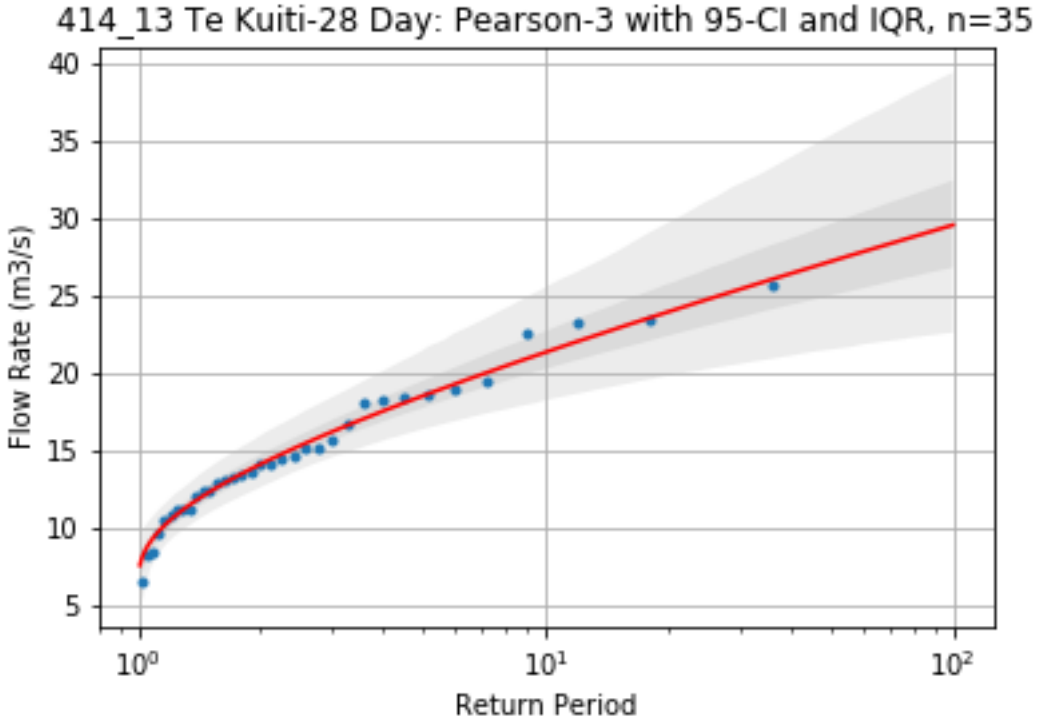

414_13 Te Kuiti-7 Day: LP-3 with 95-CI and IQR, n=35
Flow Rate (m3/s)
70
60
50
40
30
20
10
10^0
10^1
10^2
Return Period

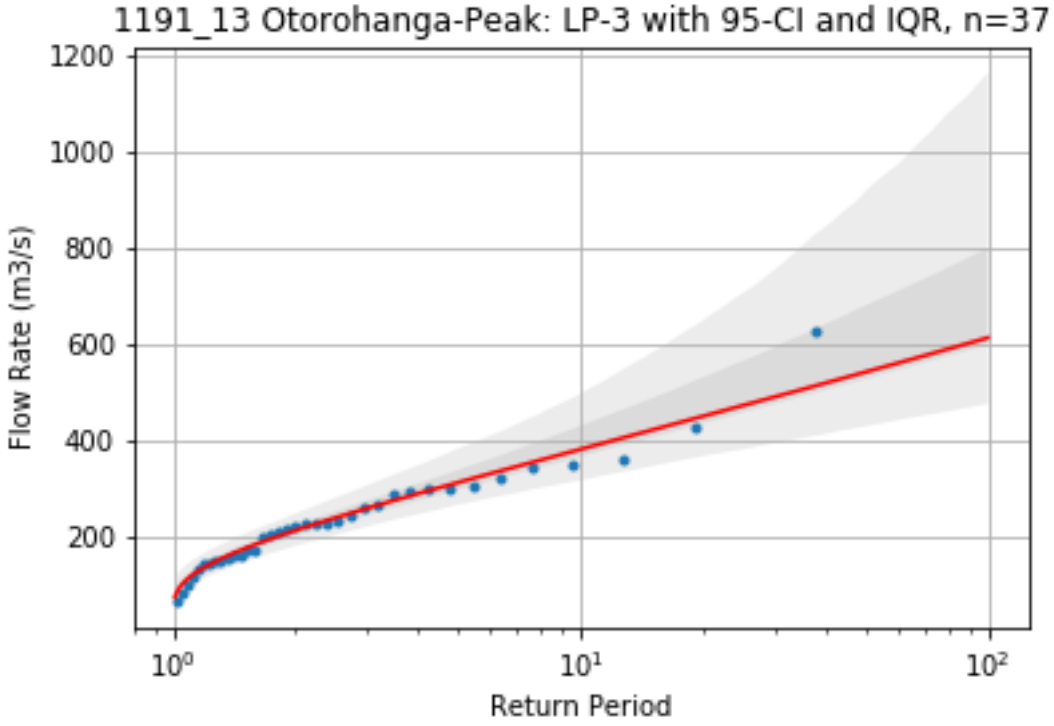

414_13 Te Kuiti-7 Day: Pearson-3 with 95-CI and IQR, n=35
Flow Rate (m3/s)
60
50
40
30
20
10
10^0
10^1
10^2
Return Period

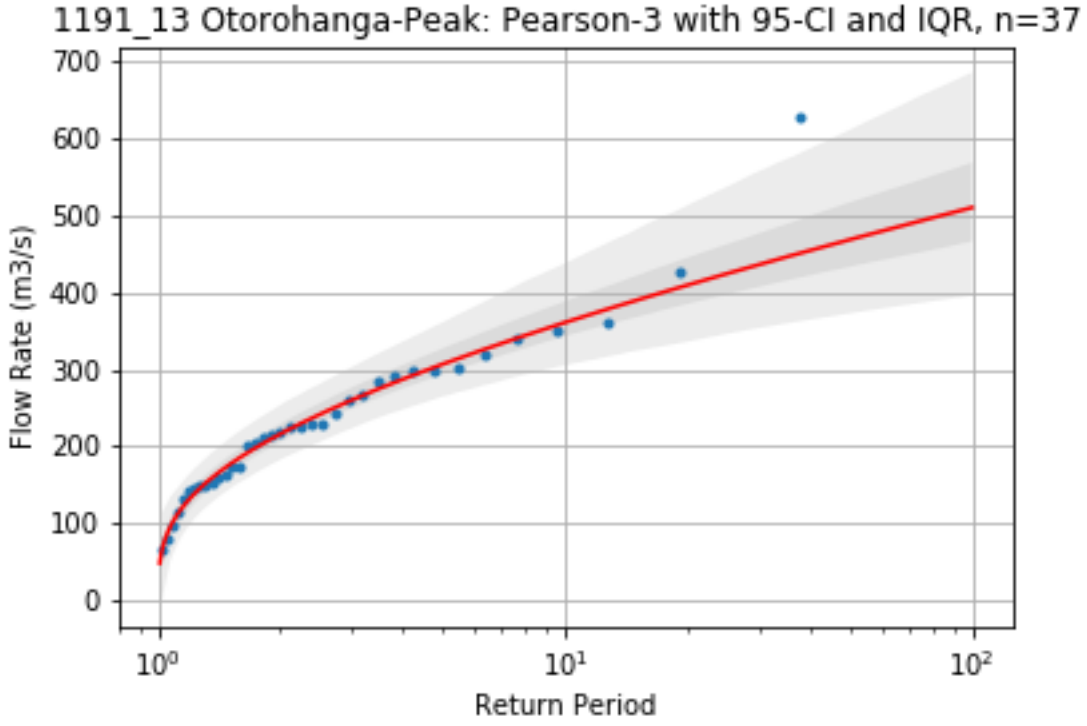

414_13 Te Kuiti-14 Day: LP-3 with 95-CI and IQR, n=35
Flow Rate (m3/s)
60
50
40
30
20
10
10^0
10^1
10^2
Return Period

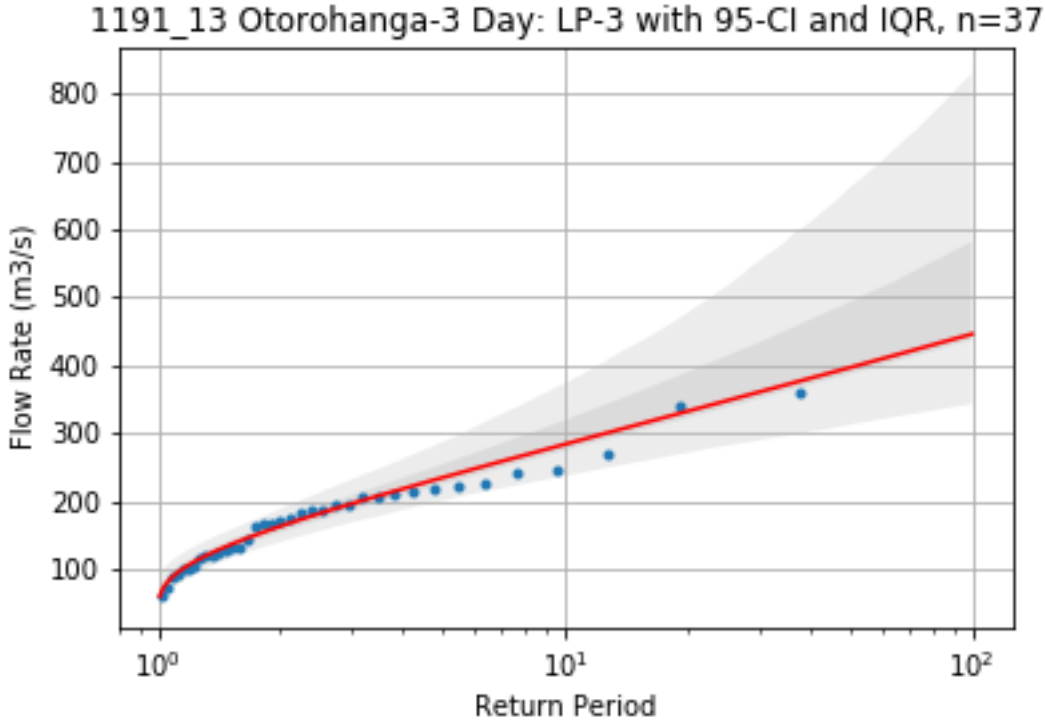

414_13 Te Kuiti-14 Day: Pearson-3 with 95-CI and IQR, n=35
Flow Rate (m3/s)
40
30
20
10
10^0
10^1
10^2
Return Period

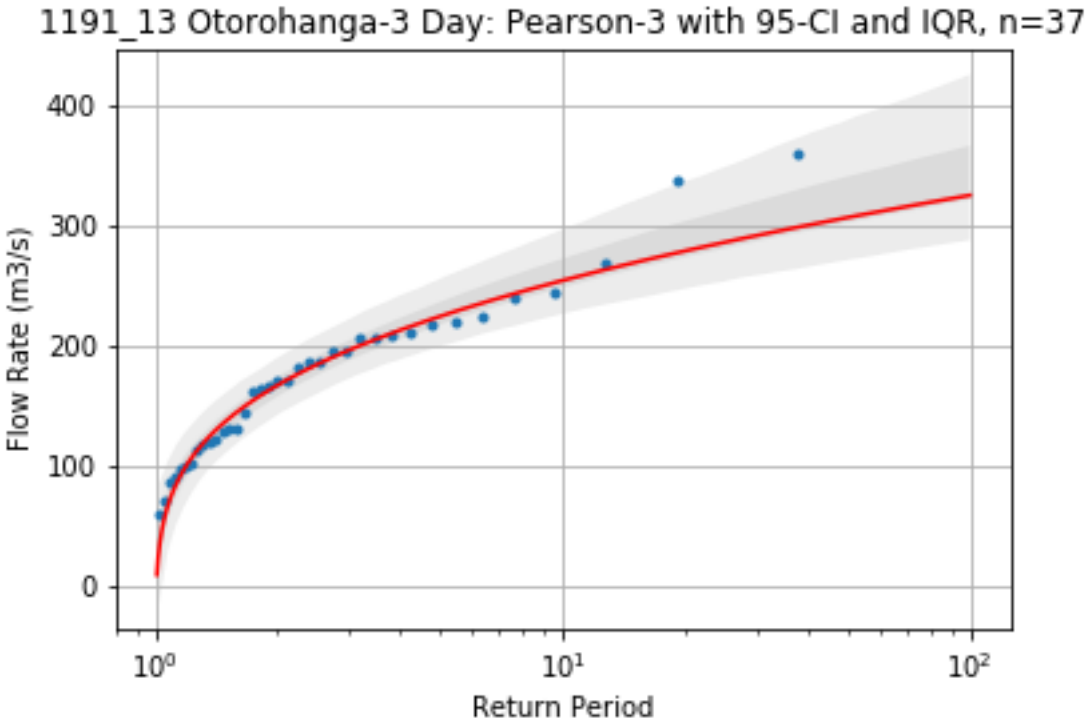

414_13 Te Kuiti-28 Day: LP-3 with 95-CI and IQR, n=35
Flow Rate (m3/s)
50
40
30
20
10
10^0
10^1
10^2
Return Period

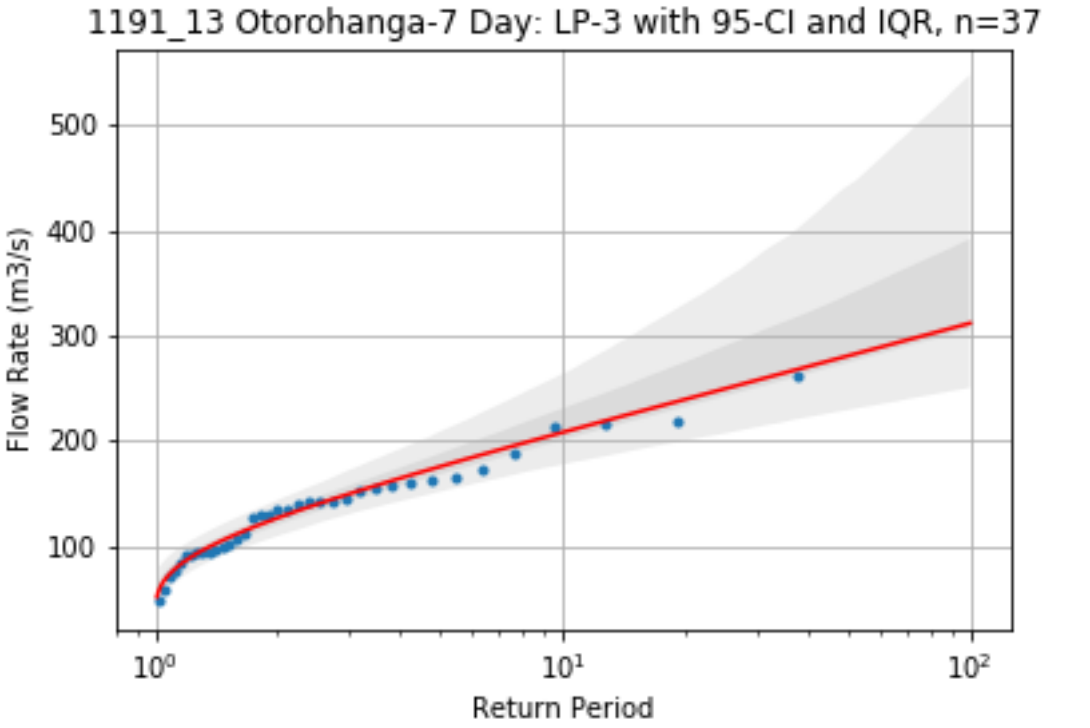

414_13 Te Kuiti-28 Day: Pearson-3 with 95-CI and IQR, n=35
Flow Rate (m3/s)
40
35
30
25
20
15
10
5
10^0
10^1
10^2
Return Period

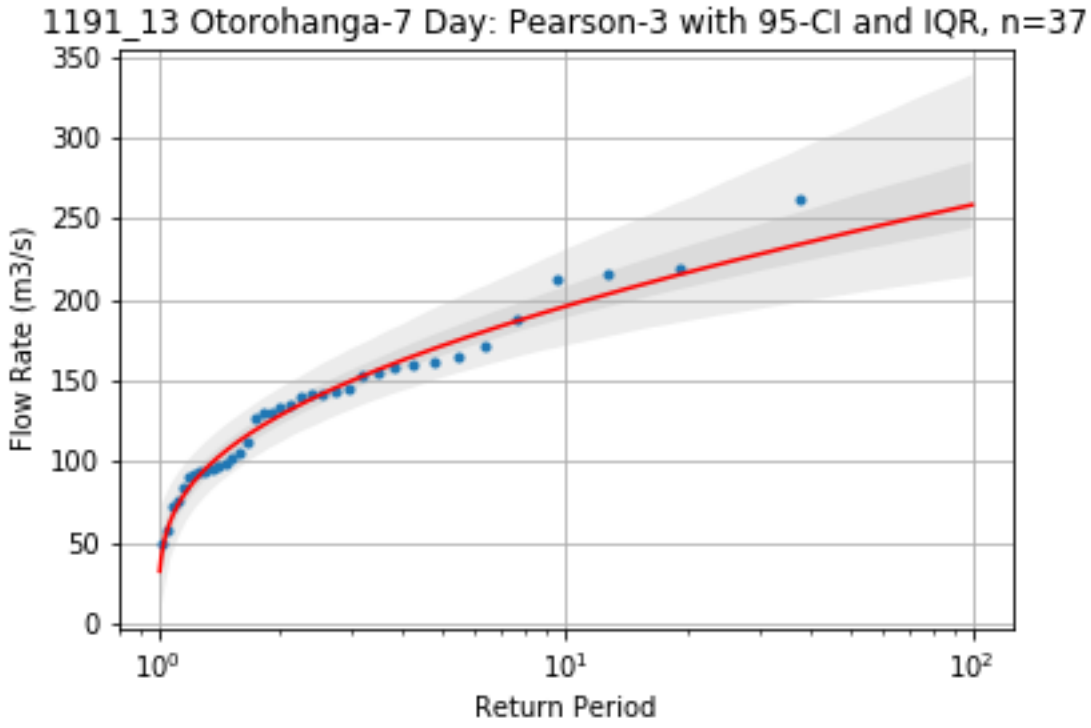

1191_13 Otorohanga-Peak: LP-3 with 95-CI and IQR, n=37
Flow Rate (m3/s)
1200
1000
800
600
400
200
10^0
10^1
10^2
Return Period

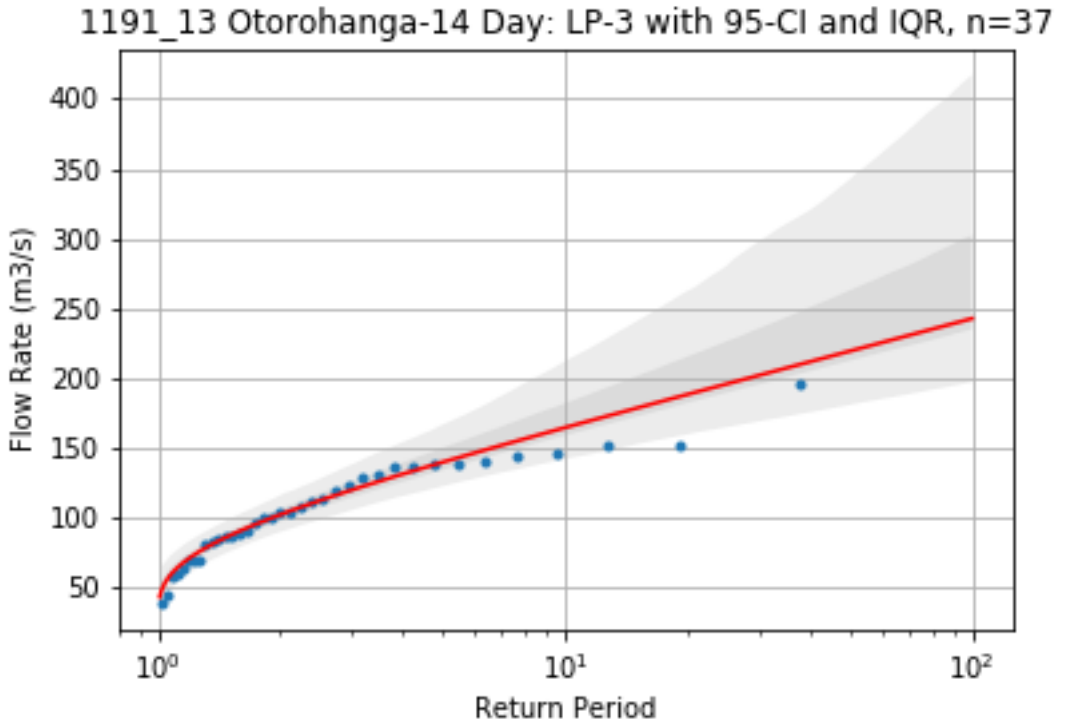

1191_13 Otorohanga-Peak: Pearson-3 with 95-CI and IQR, n=37
Flow Rate (m3/s)
Return Period

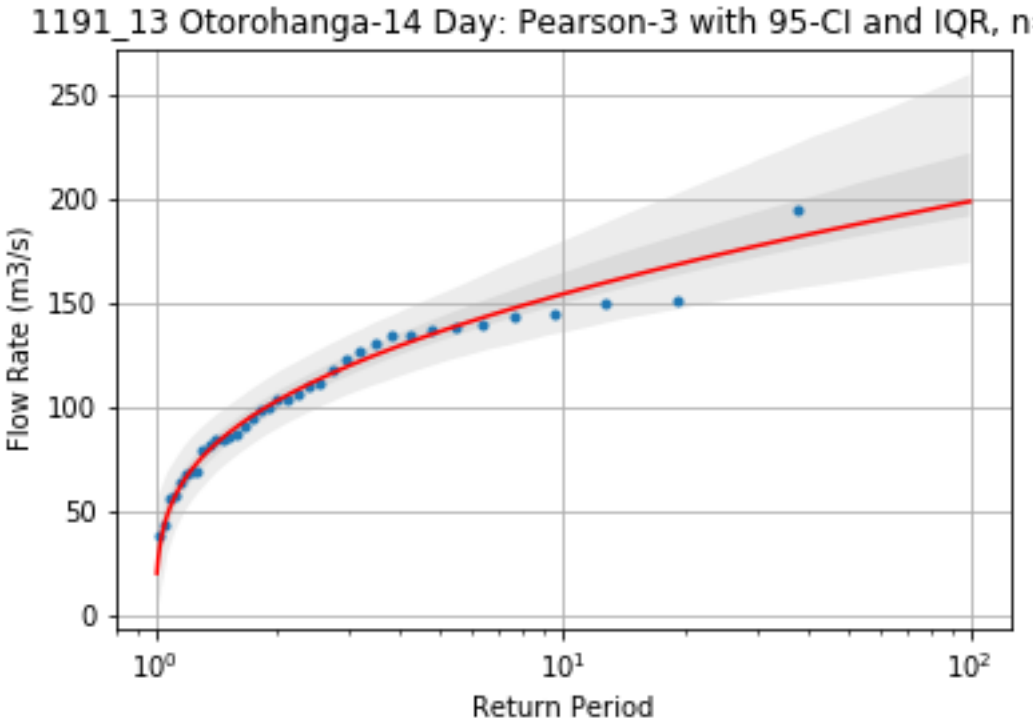

1191_13 Otorohanga-3 Day: LP-3 with 95-CI and IQR, n=37
Flow Rate (m3/s)
Return Period

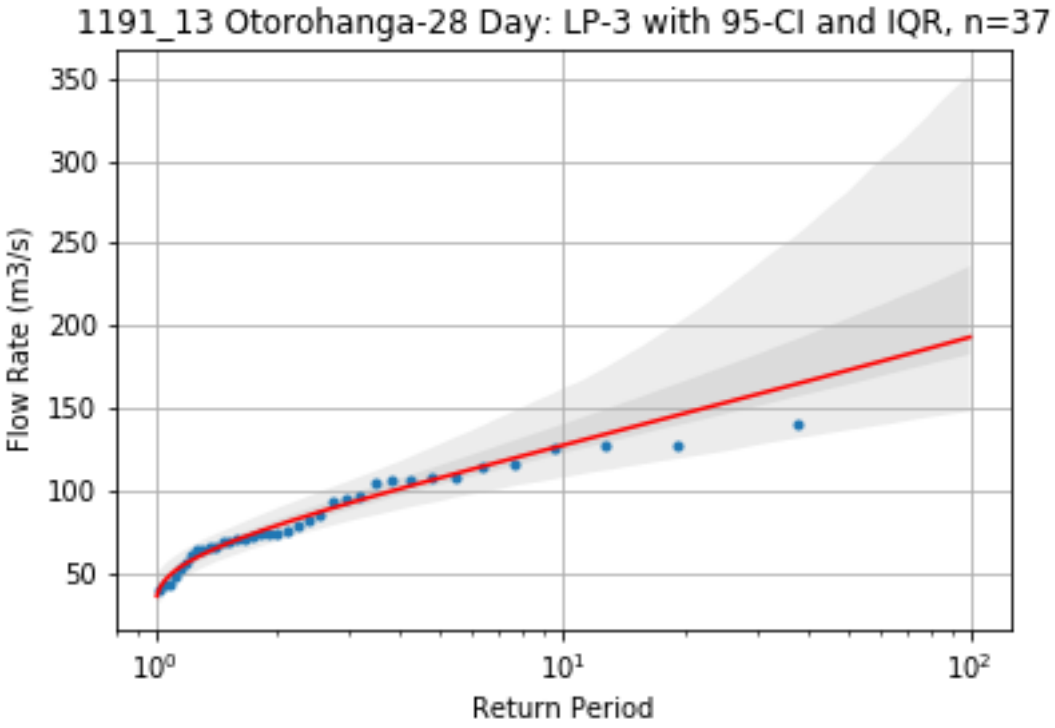

1191_13 Otorohanga-3 Day: Pearson-3 with 95-CI and IQR, n=37
Flow Rate (m3/s)
400
300
200
100
0
10^0
10^1
10^2
Return Period

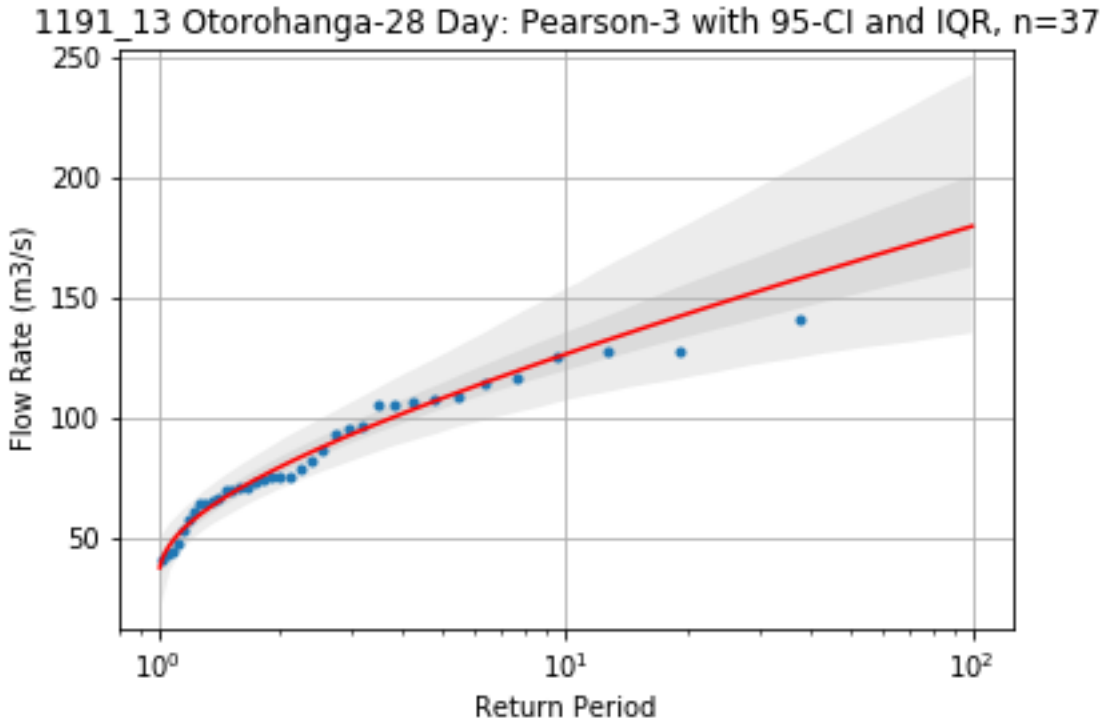

1191_13 Otorohanga-7 Day: LP-3 with 95-CI and IQR, n=37
Flow Rate (m3/s)
500
400
300
200
100
10^0
10^1
10^2
Return Period

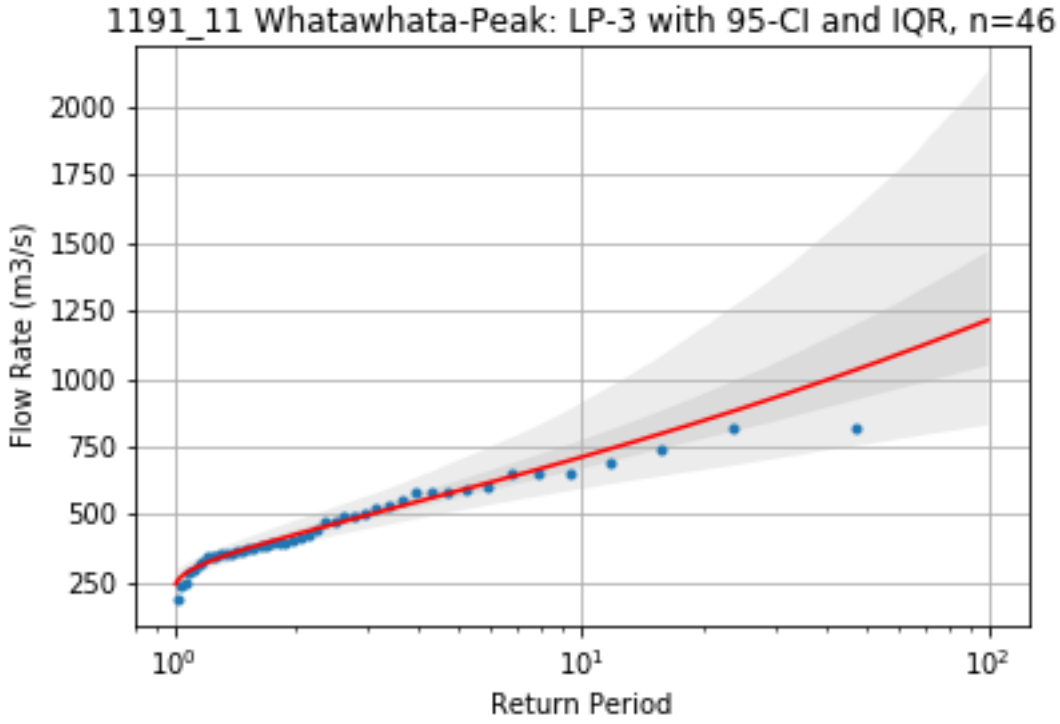

1191_13 Otorohanga-7 Day: Pearson-3 with 95-CI and IQR, n=37
Flow Rate (m3/s)
Return Period
0
50
100
150
200
250
300
350
10^0
10^1
10^2

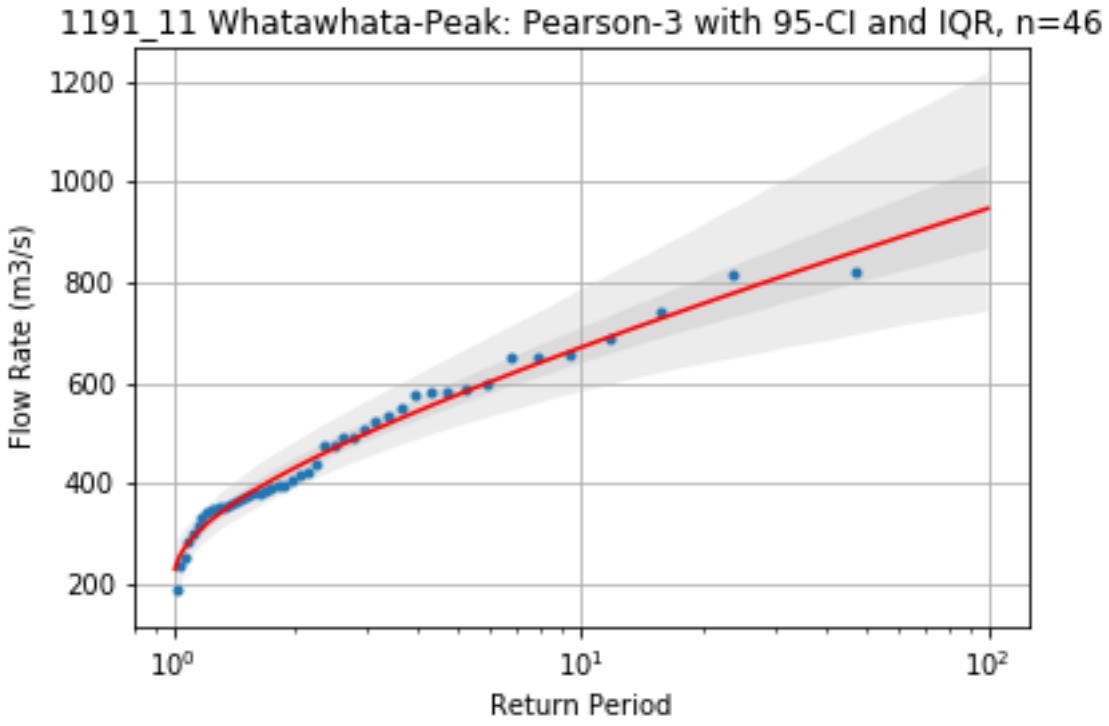

1191_13 Otorohanga-14 Day: LP-3 with 95-CI and IQR, n=37
Flow Rate (m3/s)
Return Period
50
100
150
200
250
300
350
400
10^0
10^1
10^2

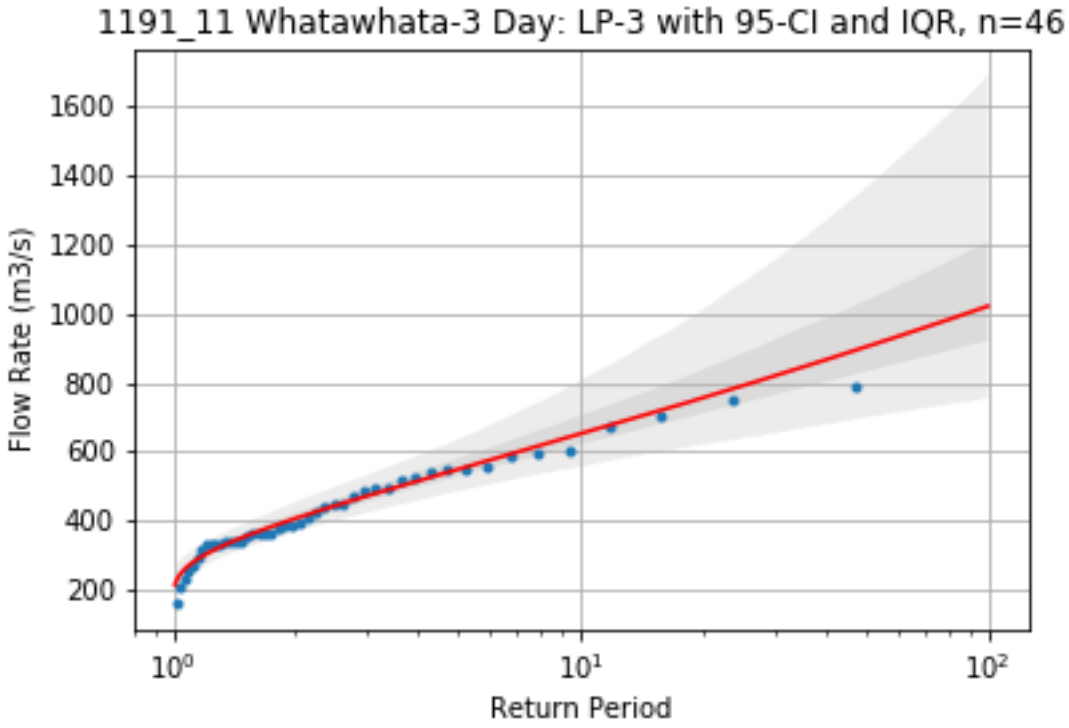

1191_13 Otorohanga-14 Day: Pearson-3 with 95-CI and IQR, n=37
Flow Rate (m3/s)
250
200
150
100
50
0
10^0
10^1
10^2
Return Period

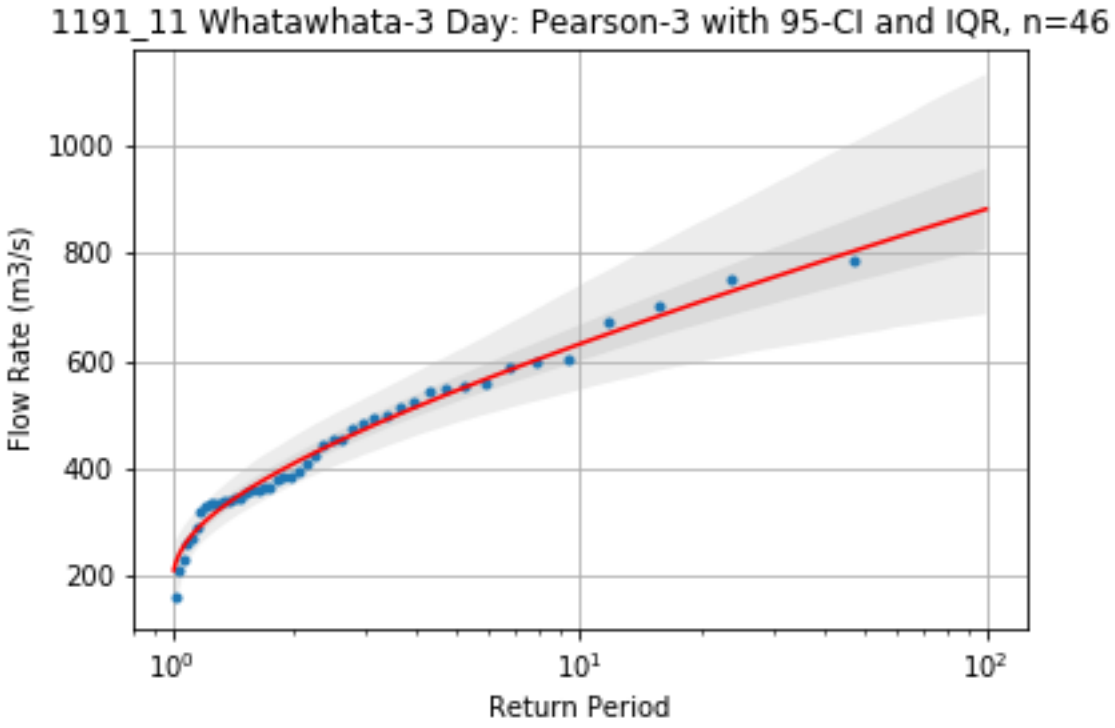

1191_13 Otorohanga-28 Day: LP-3 with 95-CI and IQR, n=37
Flow Rate (m3/s)
350
300
250
200
150
100
50
10^0
10^1
10^2
Return Period

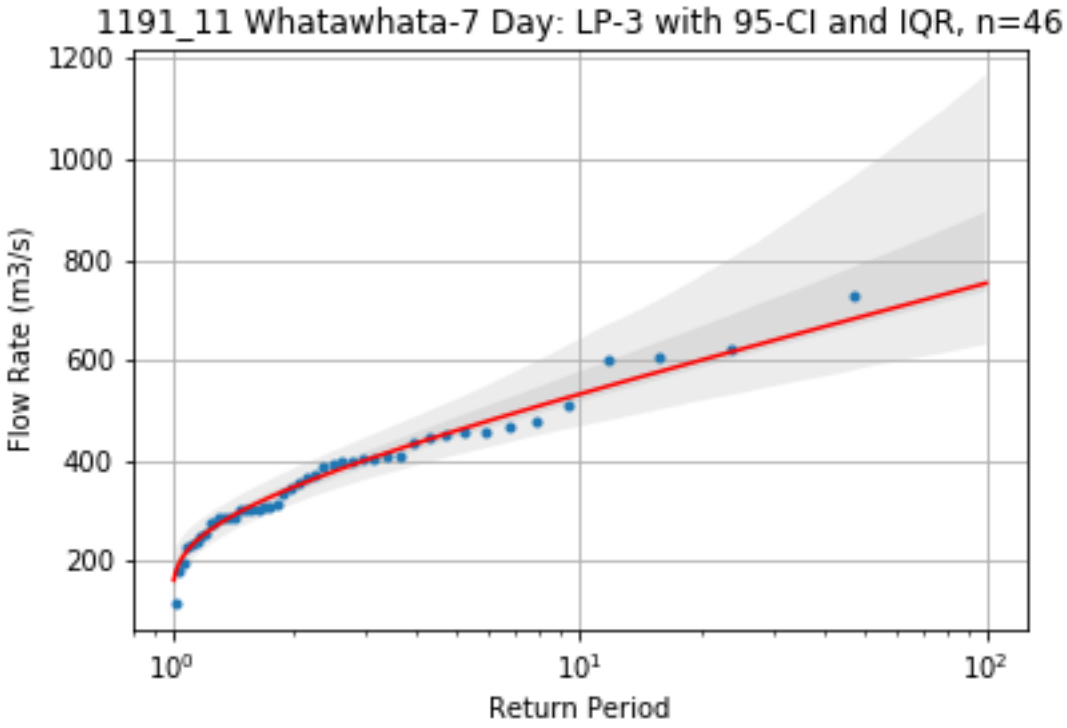

1191_13 Otorohanga-28 Day: Pearson-3 with 95-CI and IQR, n=37
Flow Rate (m3/s)
250
200
150
100
50
10^0
10^1
10^2
Return Period

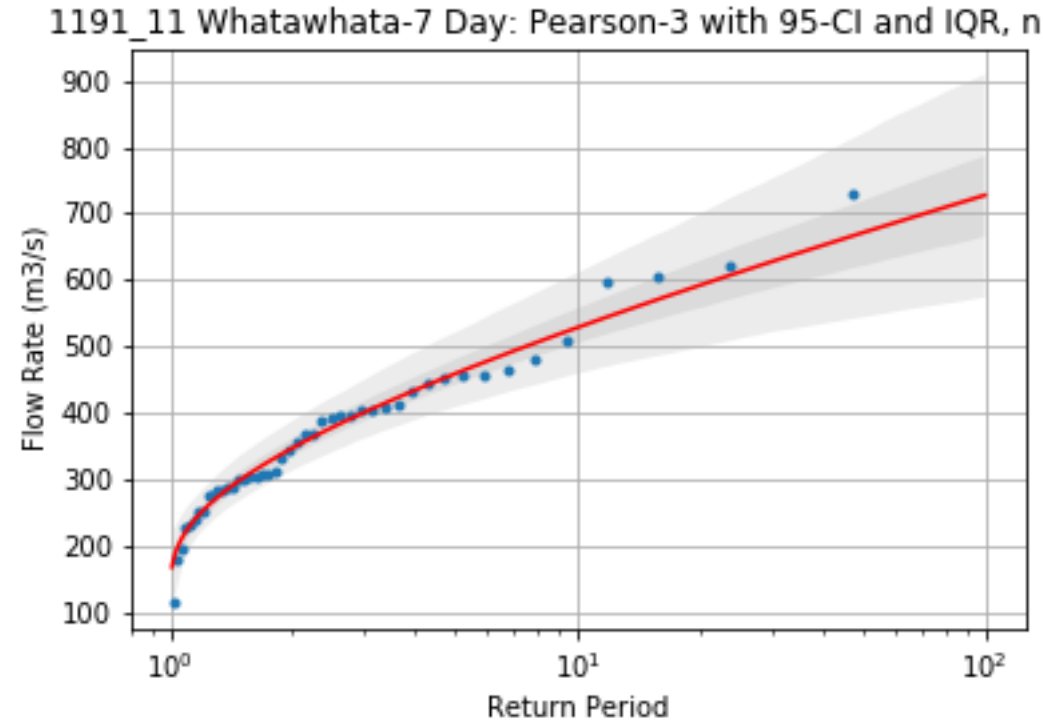

1191_11 Whatawhata-Peak: LP-3 with 95-CI and IQR, n=46
Flow Rate (m3/s)
2000
1750
1500
1250
1000
750
500
250
10^0
10^1
10^2
Return Period

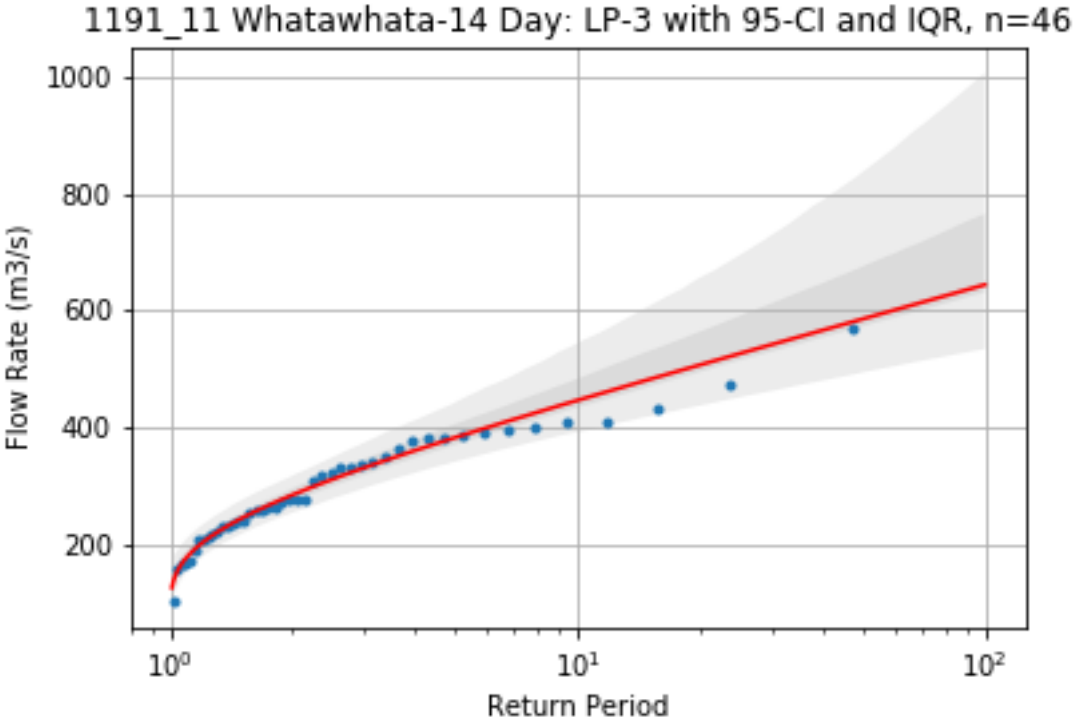

1191_11 Whatawhata-Peak: Pearson-3 with 95-CI and IQR, n=46
Flow Rate (m3/s)
1200
1000
800
600
400
200
10^0
10^1
10^2
Return Period

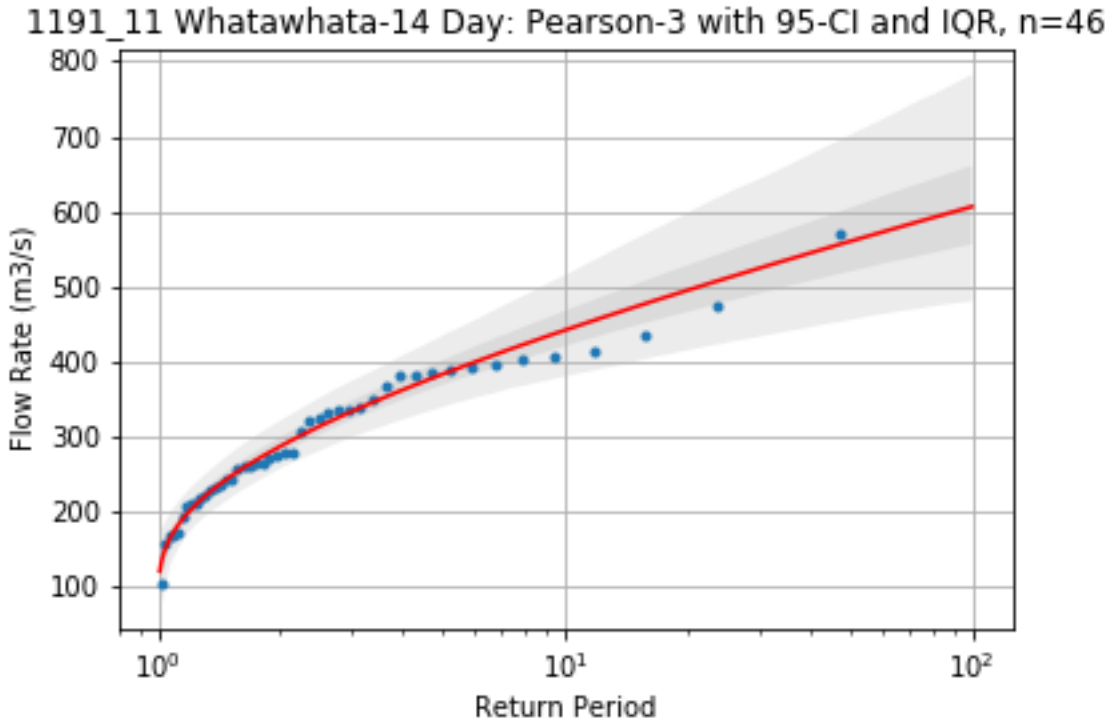

1191_11 Whatawhata-3 Day: LP-3 with 95-CI and IQR, n=46
Flow Rate (m3/s)
1600
1400
1200
1000
800
600
400
200
10^0
10^1
10^2
Return Period

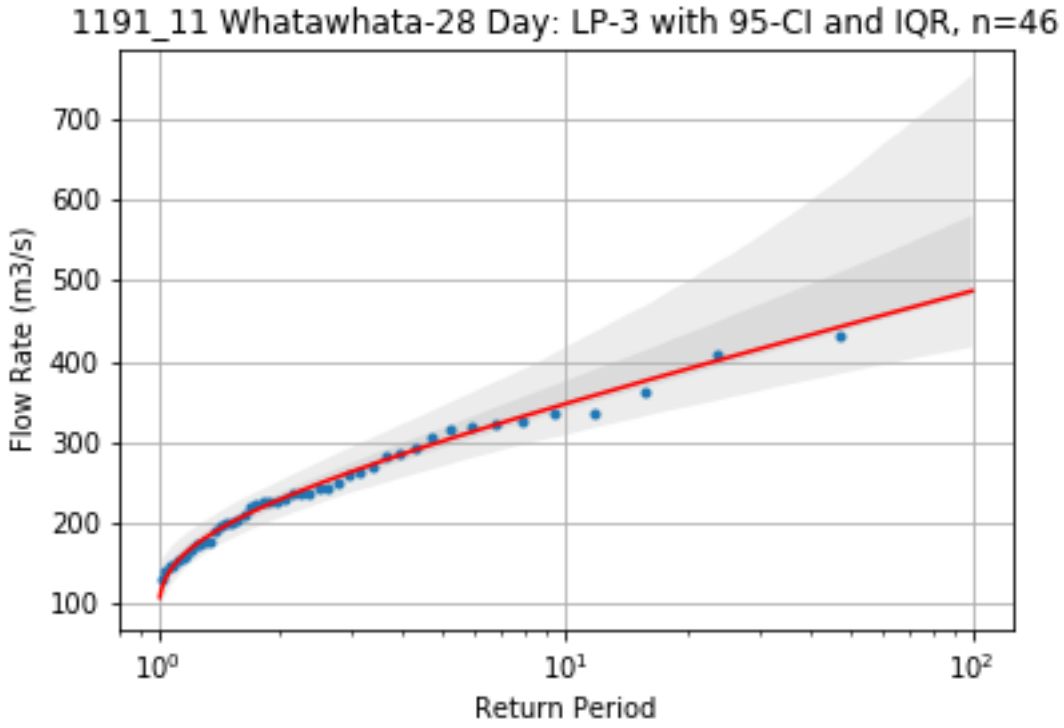

1191_11 Whatawhata-3 Day: Pearson-3 with 95-CI and IQR, n=46
Flow Rate (m3/s)
1000
800
600
400
200
10^0
10^1
10^2
Return Period

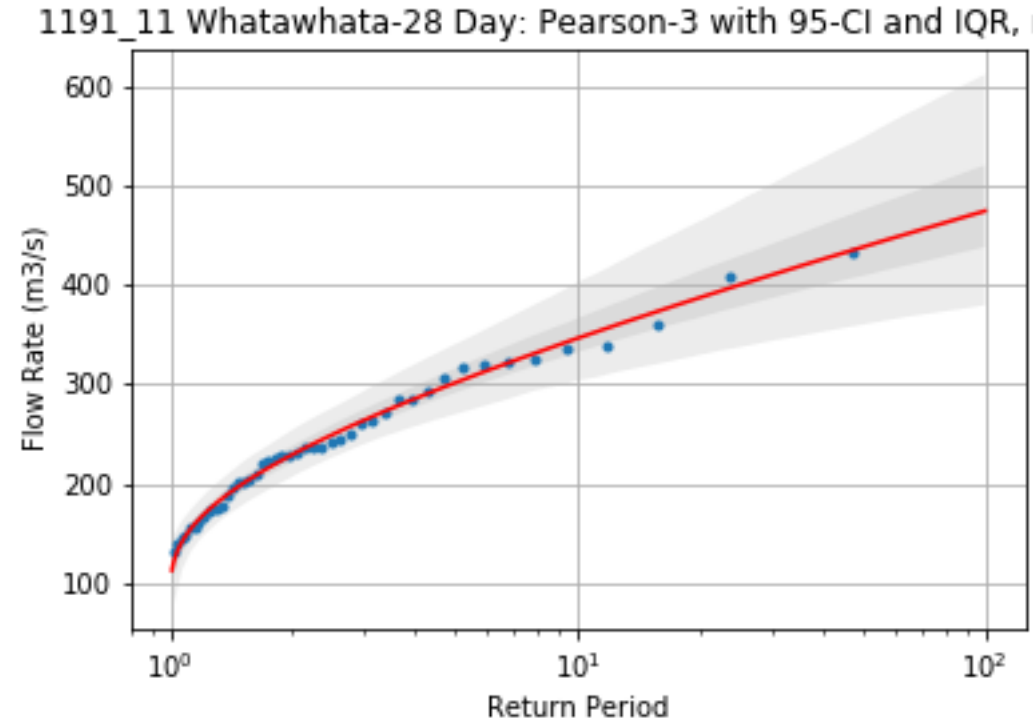

1191_11 Whatawhata-7 Day: LP-3 with 95-CI and IQR, n=46
Flow Rate (m3/s)
1200
1000
800
600
400
200
10^0
10^1
10^2
Return Period

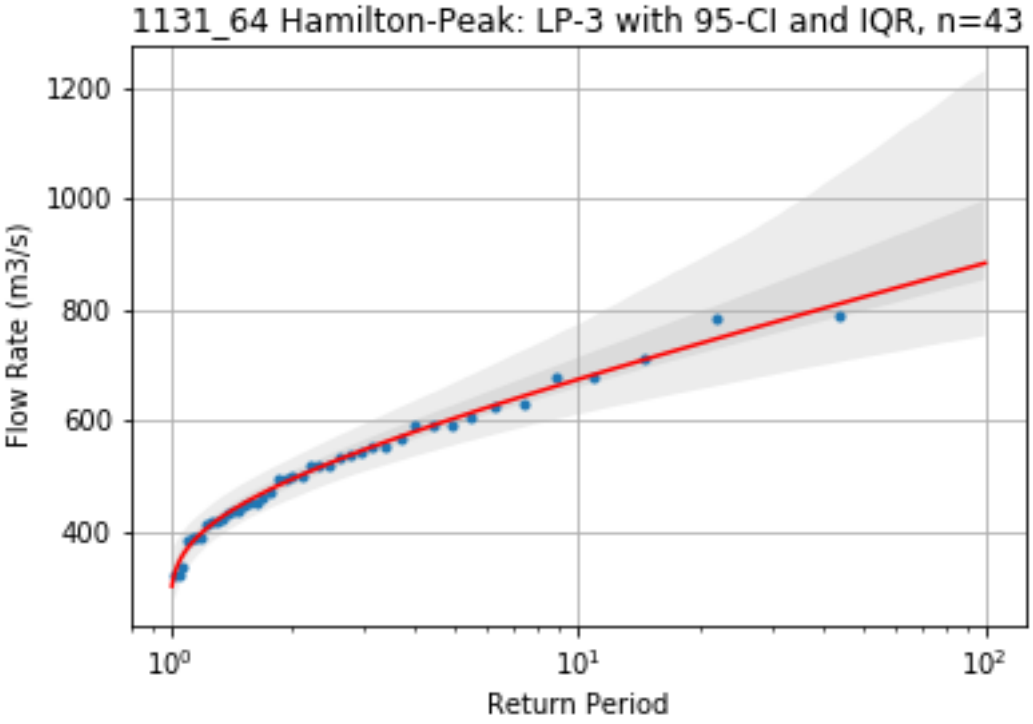

1191_11 Whatawhata-7 Day: Pearson-3 with 95-CI and IQR, n=46
Flow Rate (m3/s)
900
800
700
600
500
400
300
200
100
10^0
10^1
10^2
Return Period

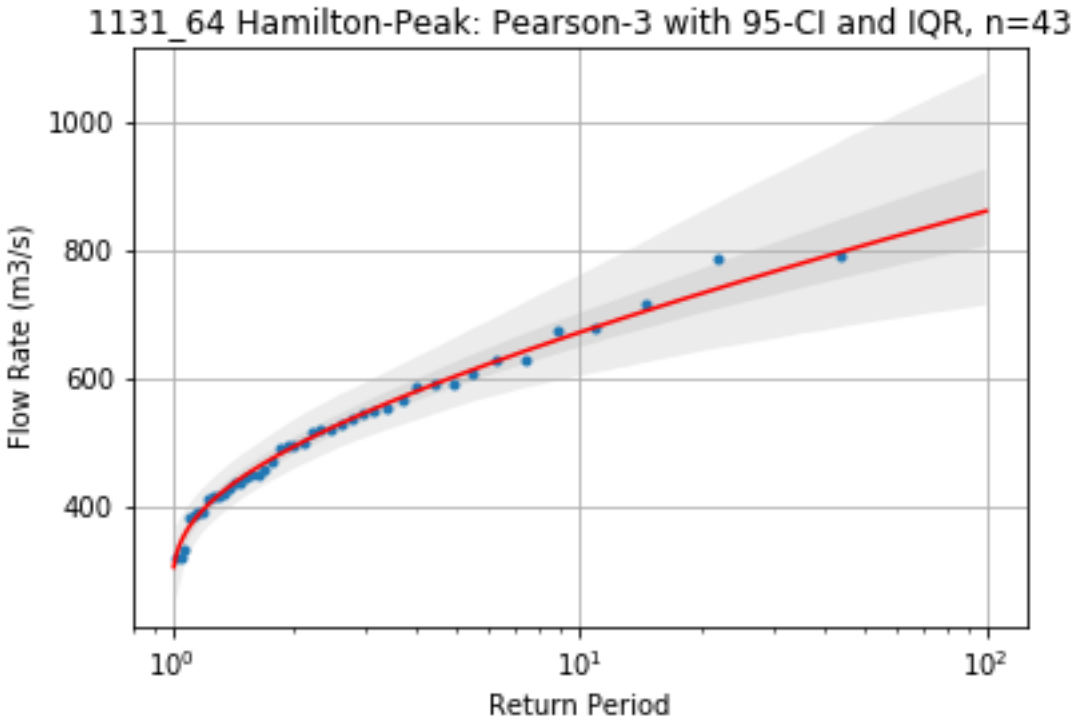

1191_11 Whatawhata-14 Day: LP-3 with 95-CI and IQR, n=46
Flow Rate (m3/s)
1000
800
600
400
200
10^0
10^1
10^2
Return Period

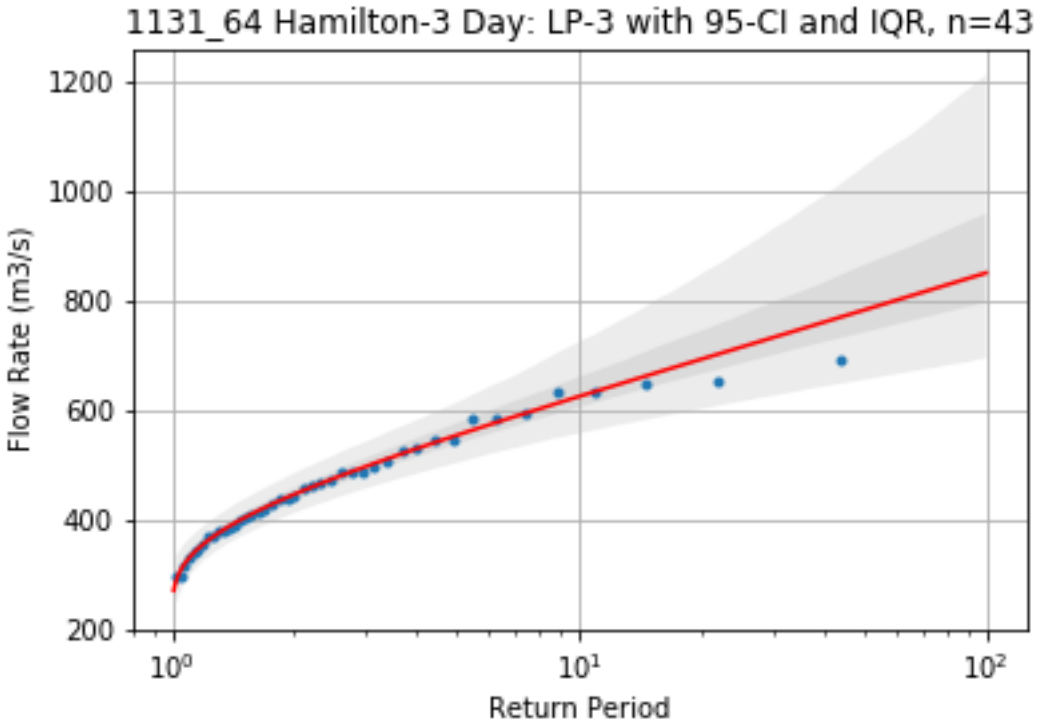

1191_11 Whatawhata-14 Day: Pearson-3 with 95-CI and IQR, n=46
Flow Rate (m3/s)
800
700
600
500
400
300
200
100
10^0
10^1
10^2
Return Period

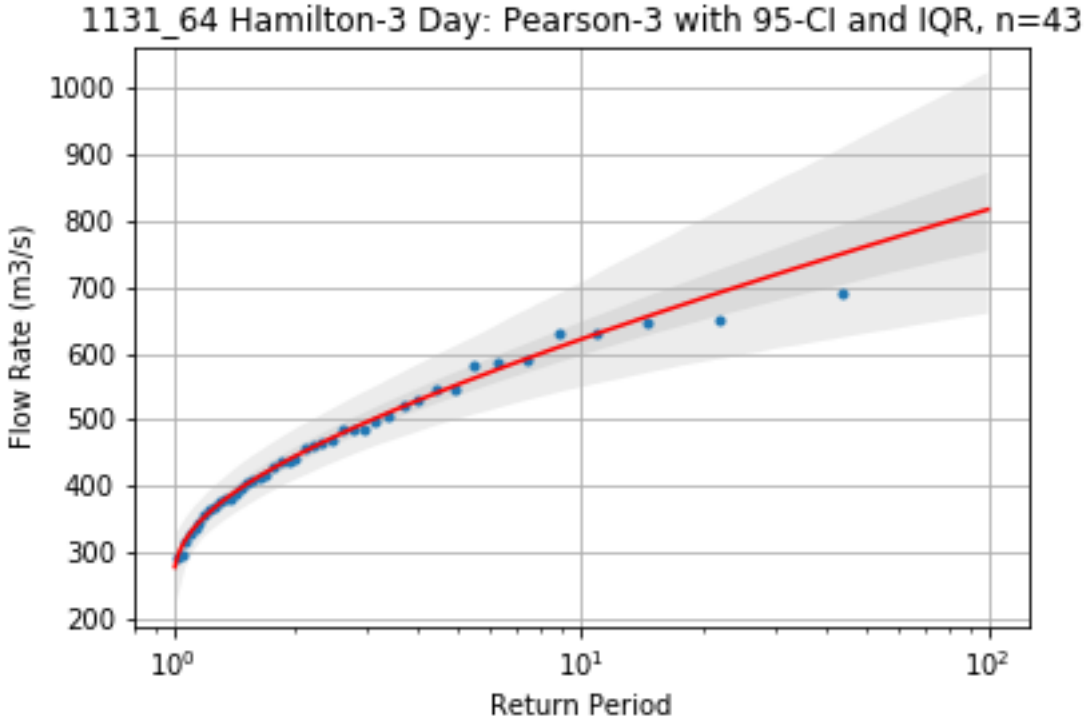

1191_11 Whatawhata-28 Day: LP-3 with 95-CI and IQR, n=46
Flow Rate (m3/s)
700
600
500
400
300
200
100
10^0
10^1
10^2
Return Period

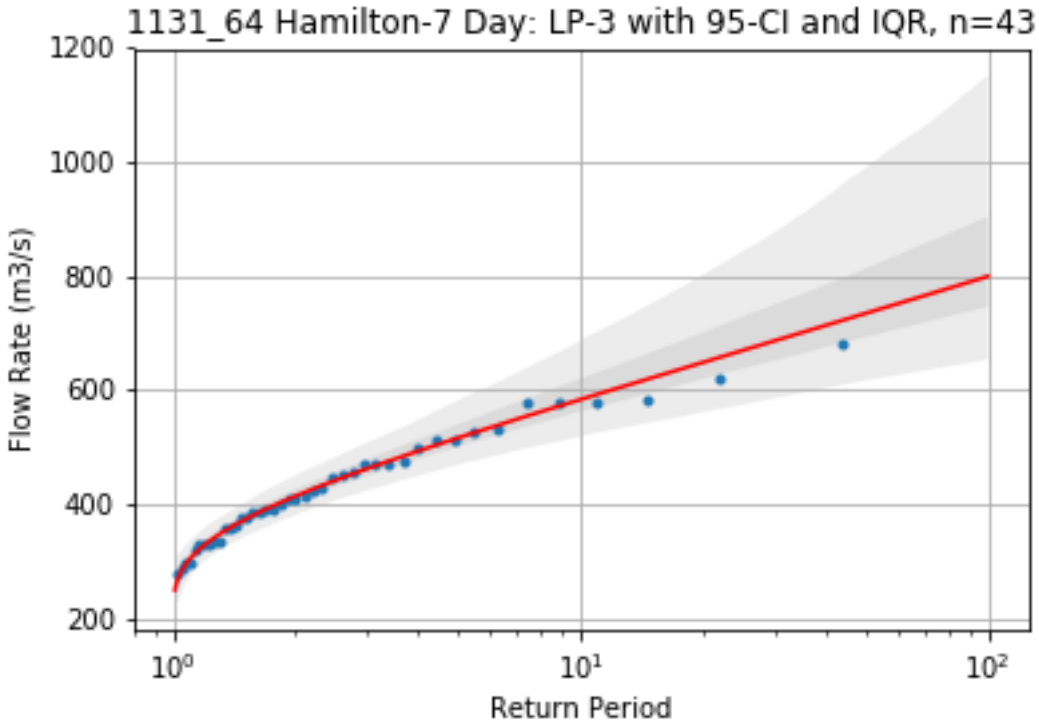

1191_11 Whatawhata-28 Day: Pearson-3 with 95-CI and IQR, n=46
Flow Rate (m3/s)
600
500
400
300
200
100
10^0
10^1
10^2
Return Period

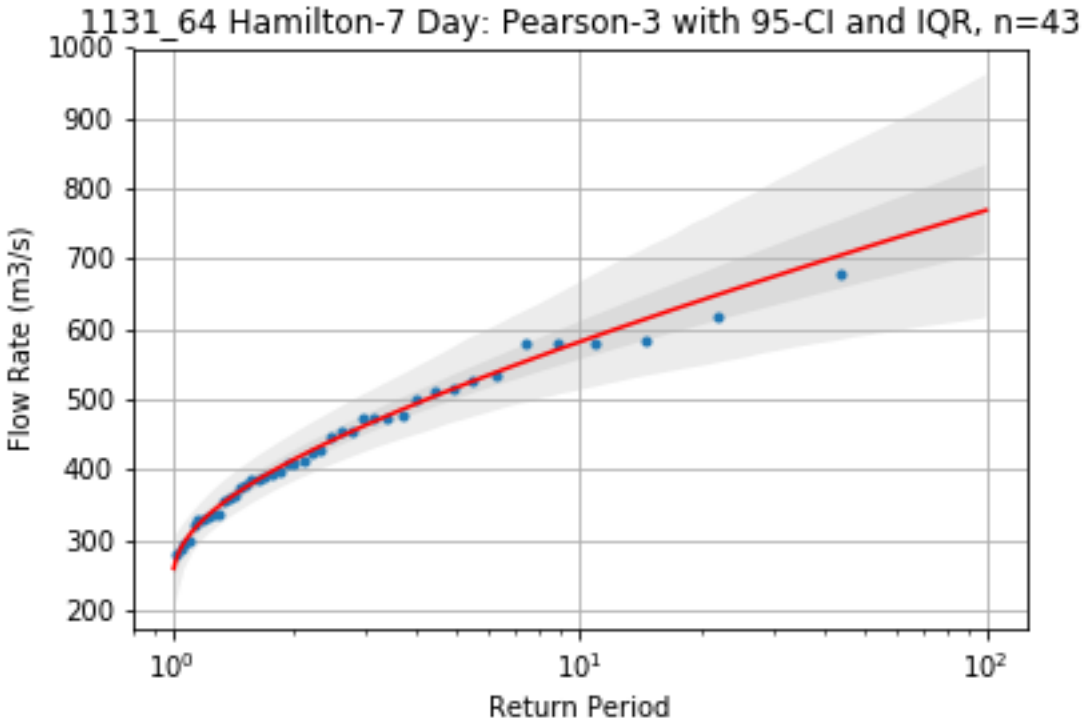

1131_64 Hamilton-Peak: LP-3 with 95-CI and IQR, n=43
Flow Rate (m3/s)
1200
1000
800
600
400
10^0
10^1
10^2
Return Period

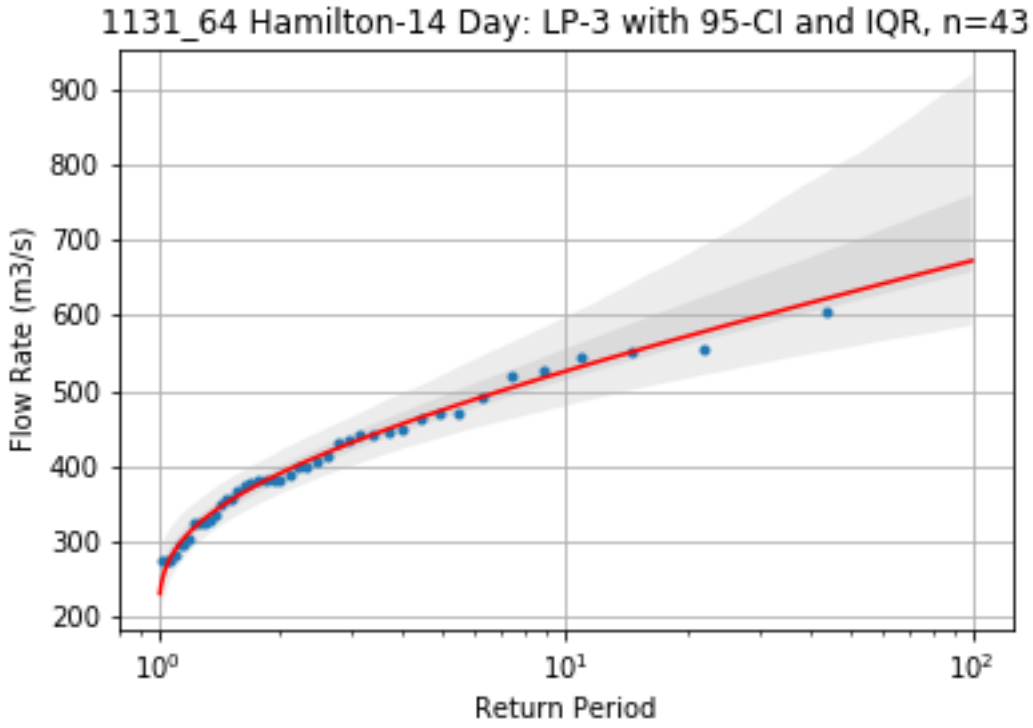

1131_64 Hamilton-Peak: Pearson-3 with 95-CI and IQR, n=43
Flow Rate (m3/s)
1000
800
600
400
10^0
10^1
10^2
Return Period

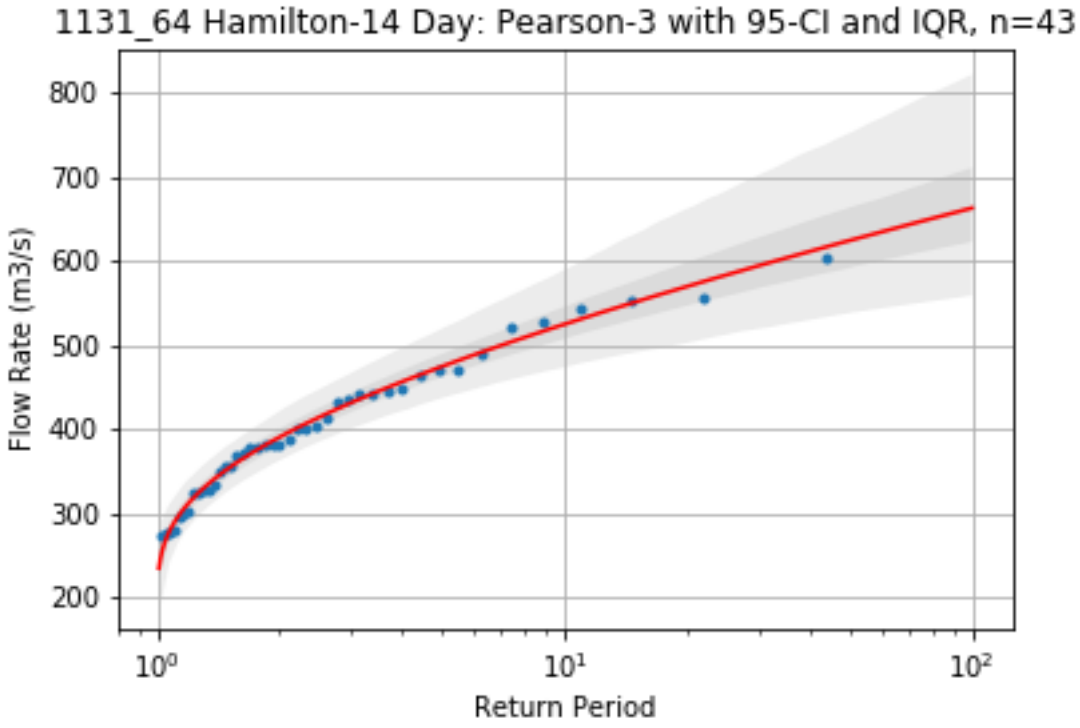

1131_64 Hamilton-3 Day: LP-3 with 95-CI and IQR, n=43
Flow Rate (m3/s)
1200
1000
800
600
400
200
10^0
10^1
10^2
Return Period

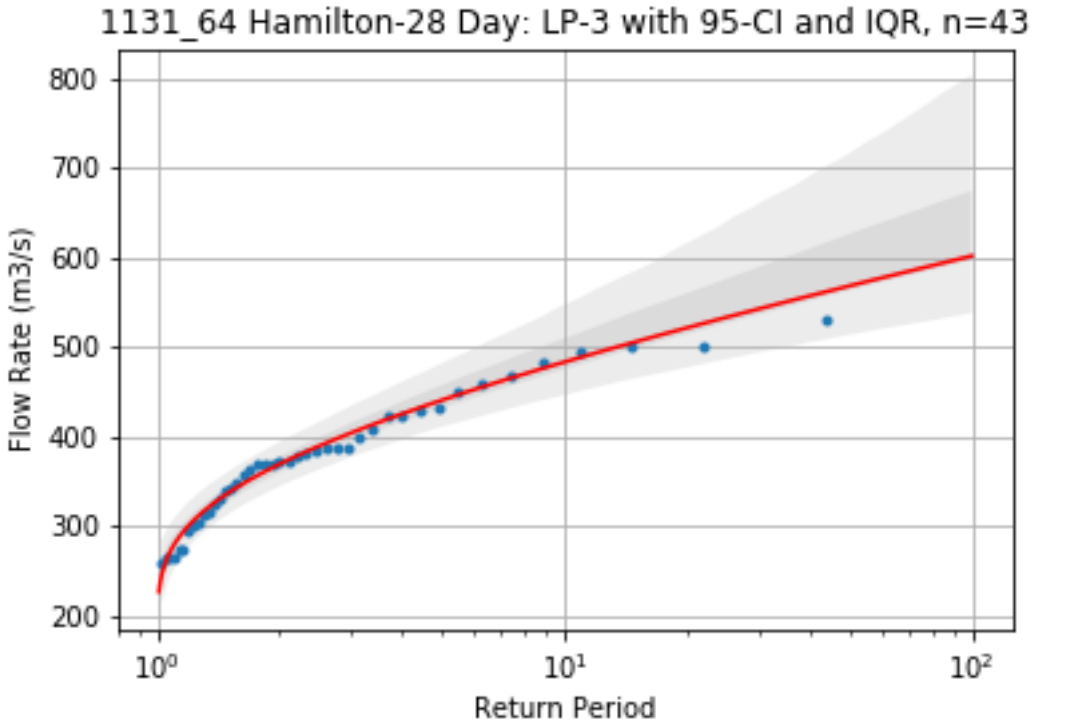

1131_64 Hamilton-3 Day: Pearson-3 with 95-CI and IQR, n=43
Flow Rate (m3/s)
1000
900
800
700
600
500
400
300
200
10^0
10^1
10^2
Return Period

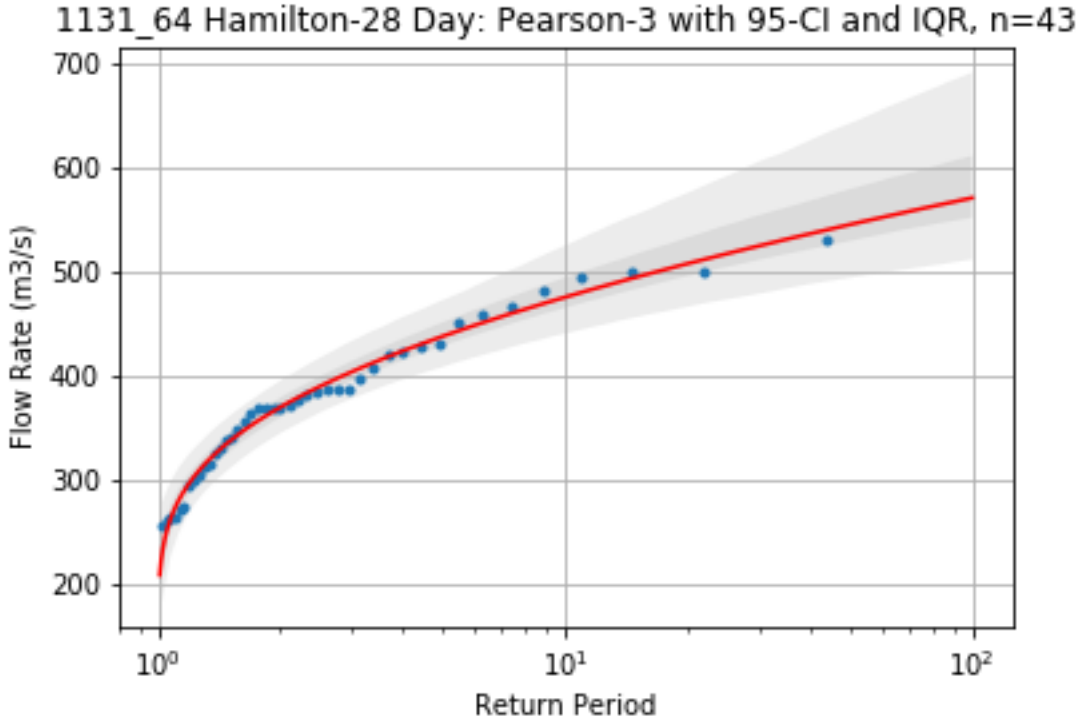

1131_64 Hamilton-7 Day: LP-3 with 95-CI and IQR, n=43
Flow Rate (m3/s)
1200
1000
800
600
400
200
10^0
10^1
10^2
Return Period

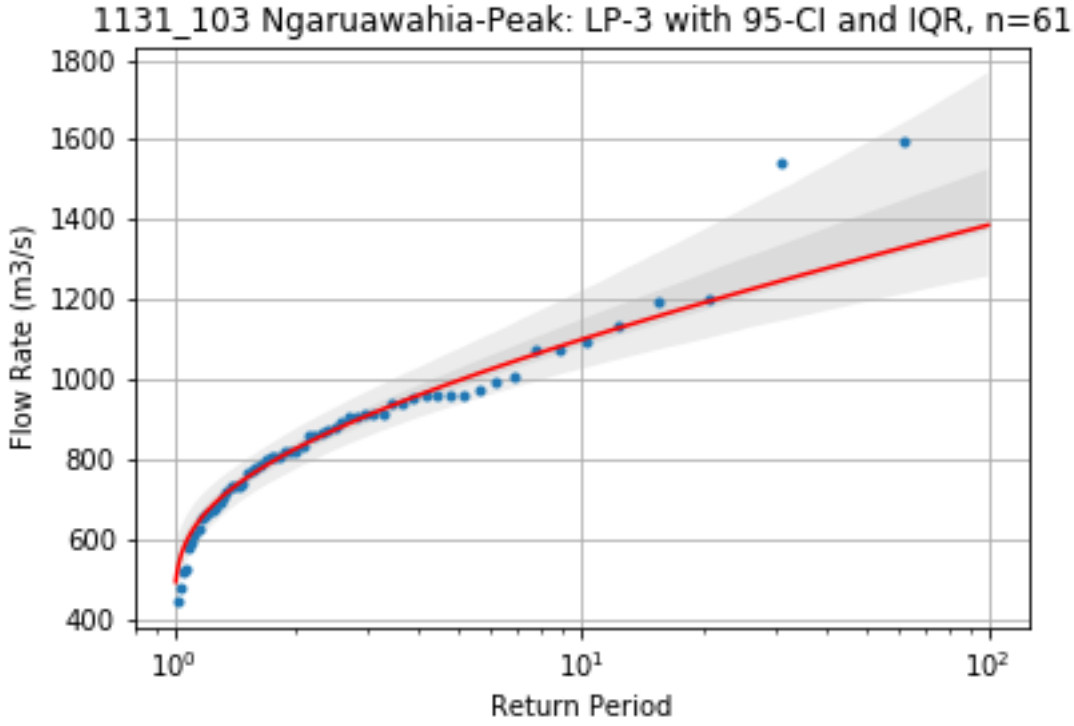

1131_64 Hamilton-7 Day: Pearson-3 with 95-CI and IQR, n=43
Flow Rate (m3/s)
Return Period

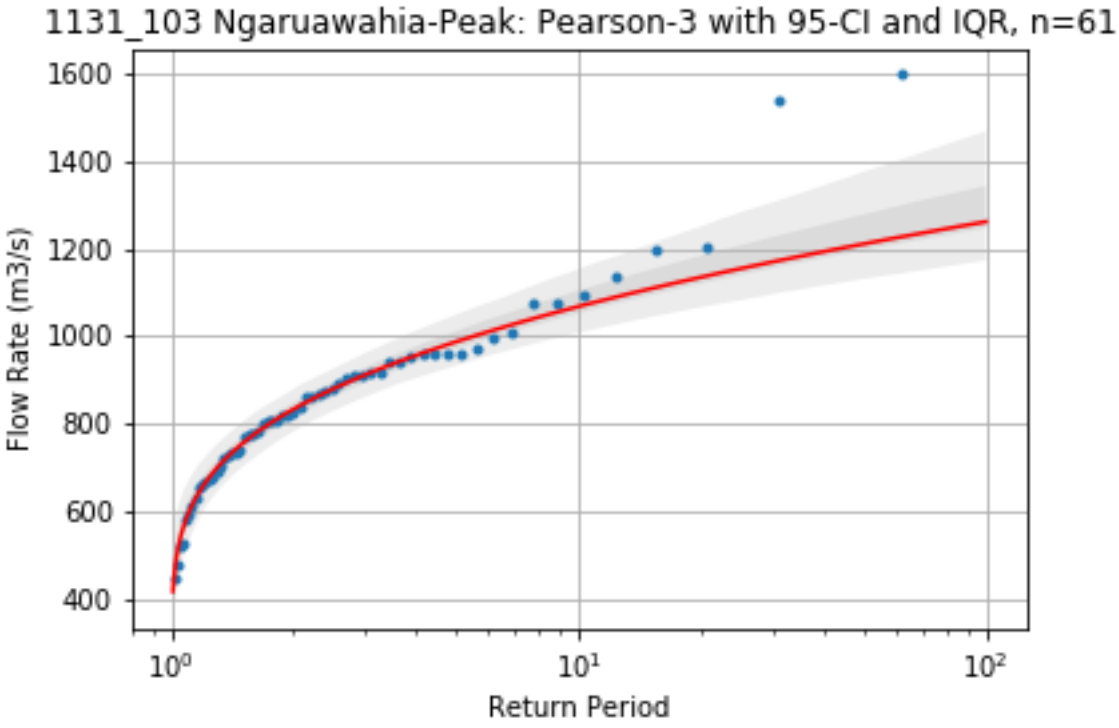

1131_64 Hamilton-14 Day: LP-3 with 95-CI and IQR, n=43
Flow Rate (m3/s)
Return Period

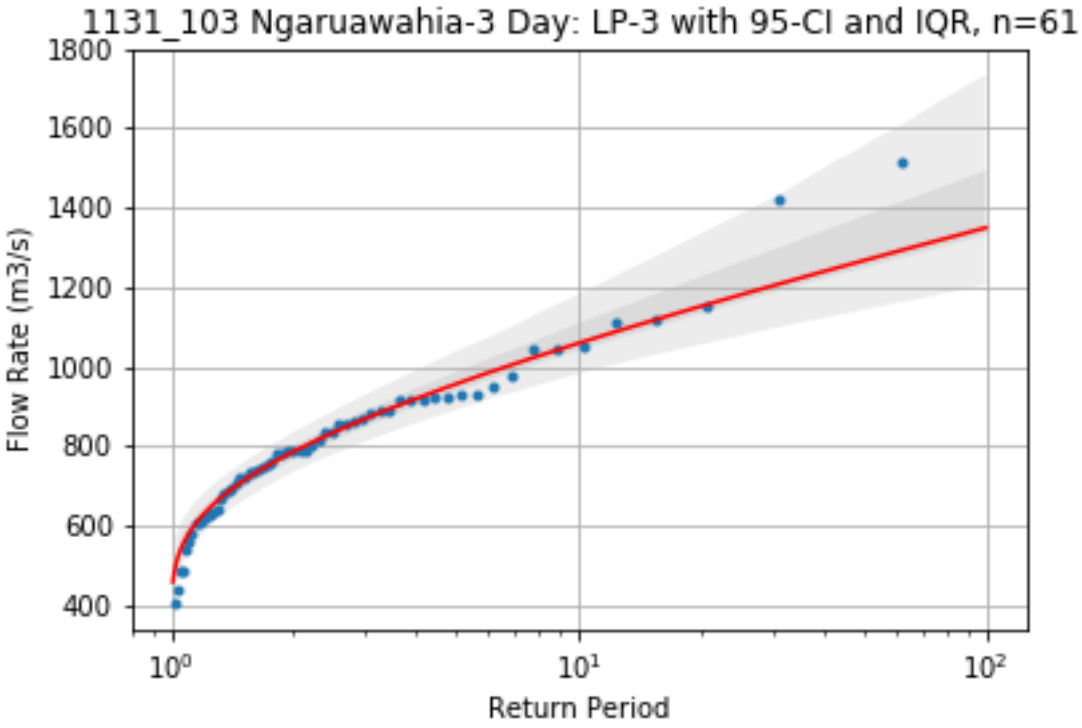

1131_64 Hamilton-14 Day: Pearson-3 with 95-CI and IQR, n=43
Flow Rate (m3/s)
800
700
600
500
400
300
200
10^0
10^1
10^2
Return Period

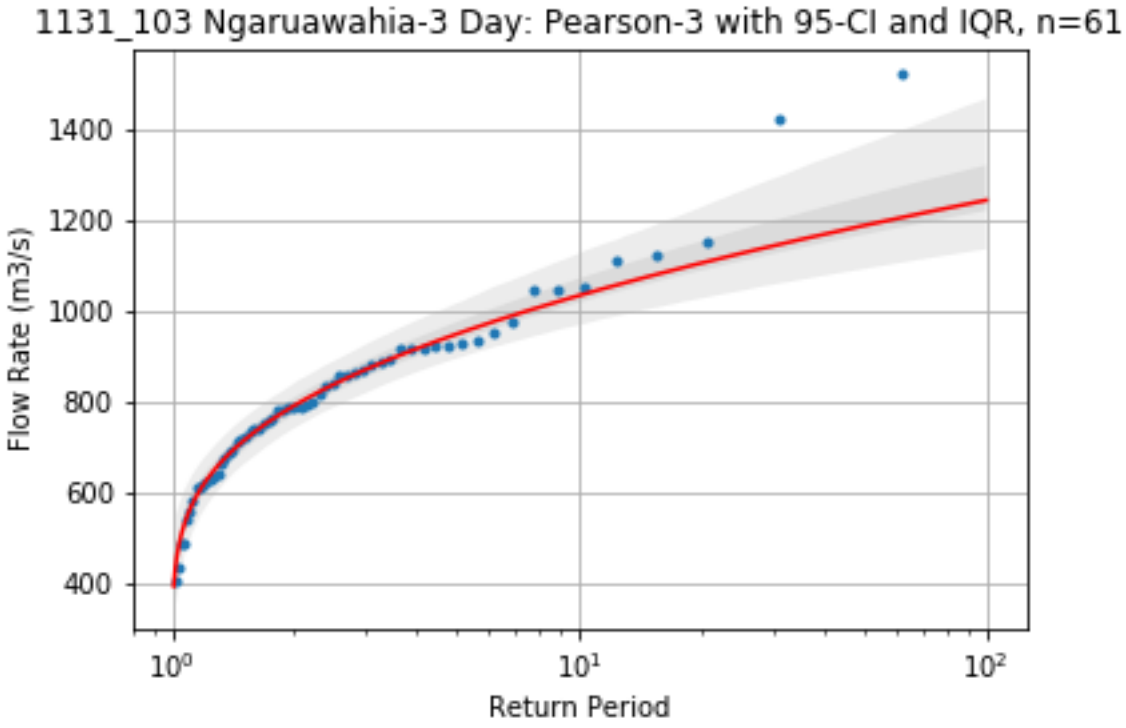

1131_64 Hamilton-28 Day: LP-3 with 95-CI and IQR, n=43
Flow Rate (m3/s)
800
700
600
500
400
300
200
10^0
10^1
10^2
Return Period

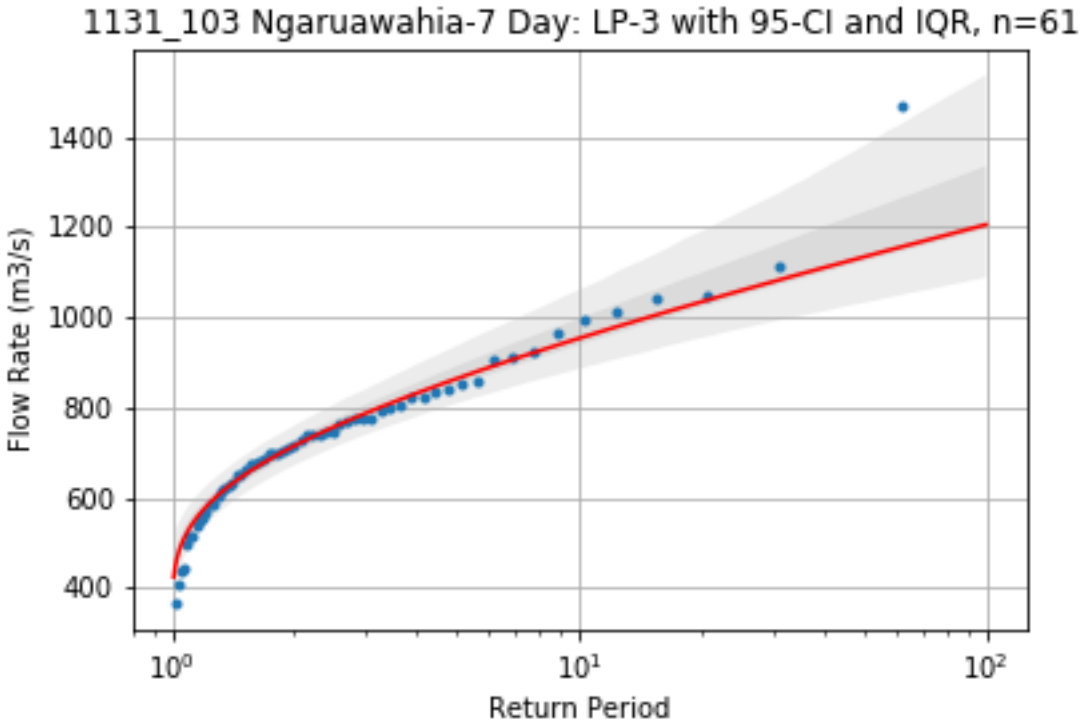

1131_64 Hamilton-28 Day: Pearson-3 with 95-CI and IQR, n=43
Flow Rate (m3/s)
700
600
500
400
300
200
10^0
10^1
10^2
Return Period

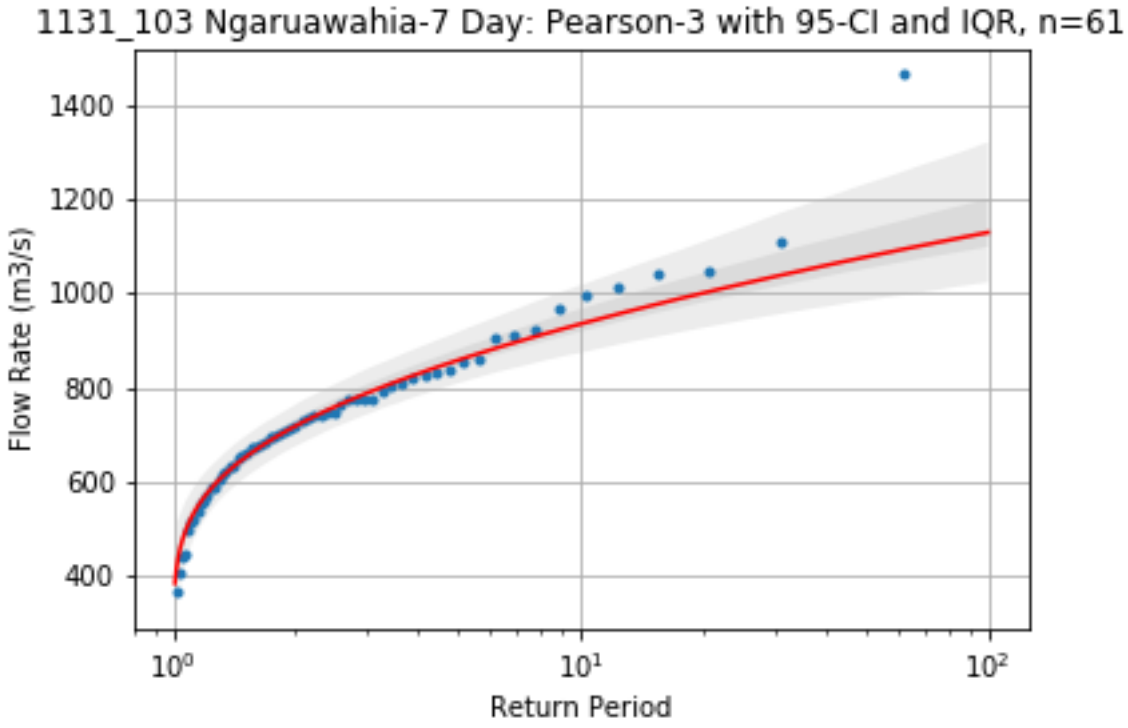

1131_103 Ngaruawahia-Peak: LP-3 with 95-CI and IQR, n=61
Flow Rate (m3/s)
1800
1600
1400
1200
1000
800
600
400
10^0
10^1
10^2
Return Period

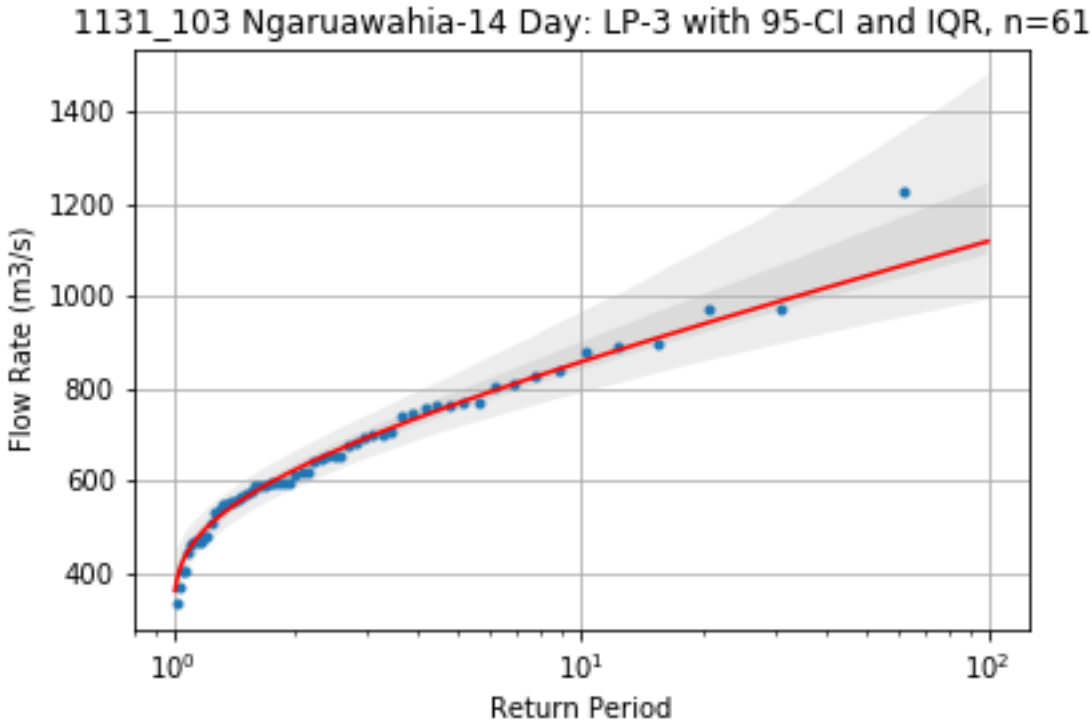

1131_103 Ngaruawahia-Peak: Pearson-3 with 95-CI and IQR, n=61
Flow Rate (m3/s)
1600
1400
1200
1000
800
600
400
10^0
10^1
10^2
Return Period

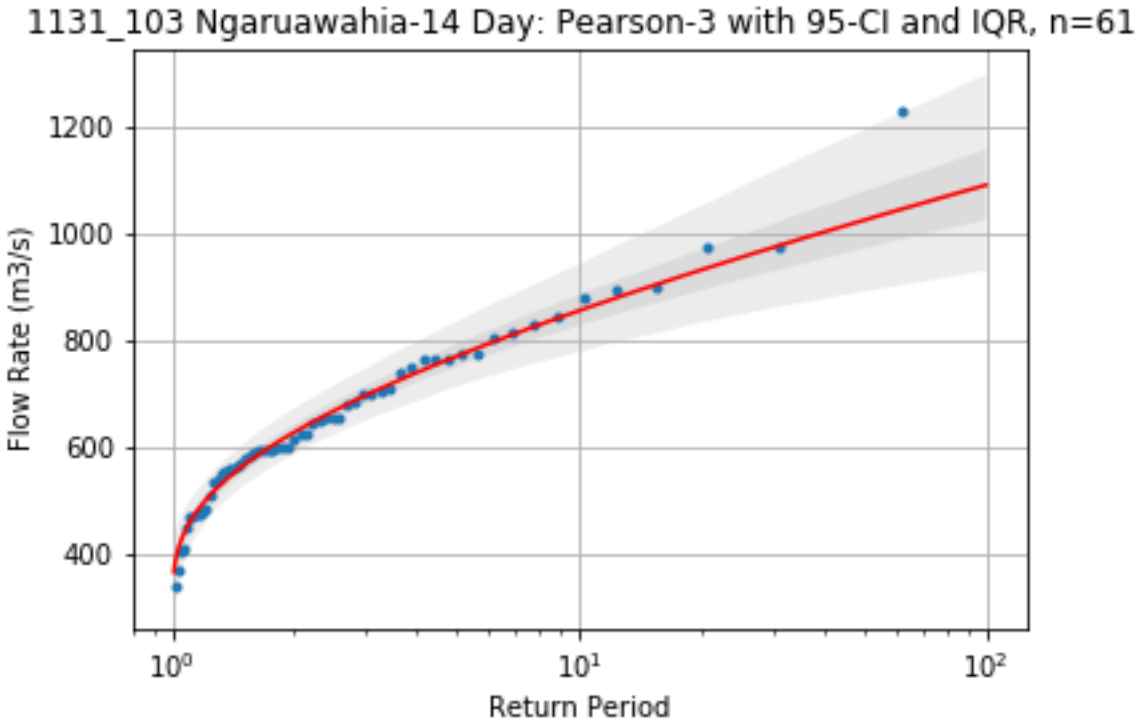

1131_103 Ngaruawahia-3 Day: LP-3 with 95-CI and IQR, n=61
Flow Rate (m3/s)
1800
1600
1400
1200
1000
800
600
400
10^0
10^1
10^2
Return Period

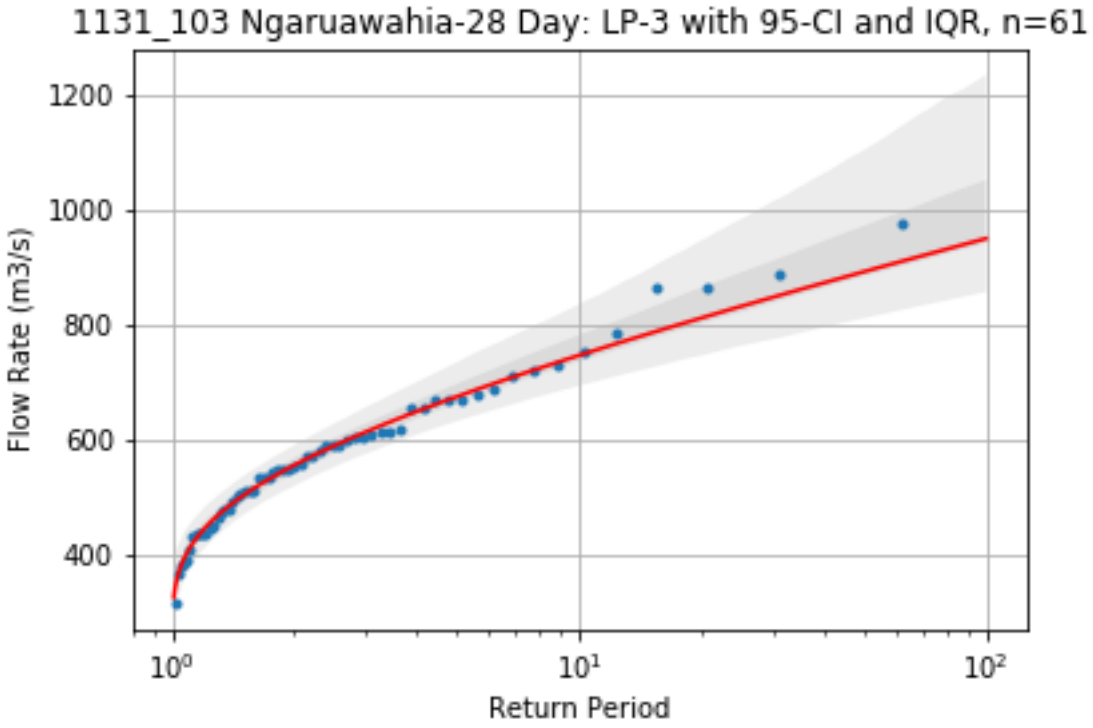

1131_103 Ngaruawahia-3 Day: Pearson-3 with 95-CI and IQR, n=61
Flow Rate (m3/s)
1400
1200
1000
800
600
400
10^0
10^1
10^2
Return Period

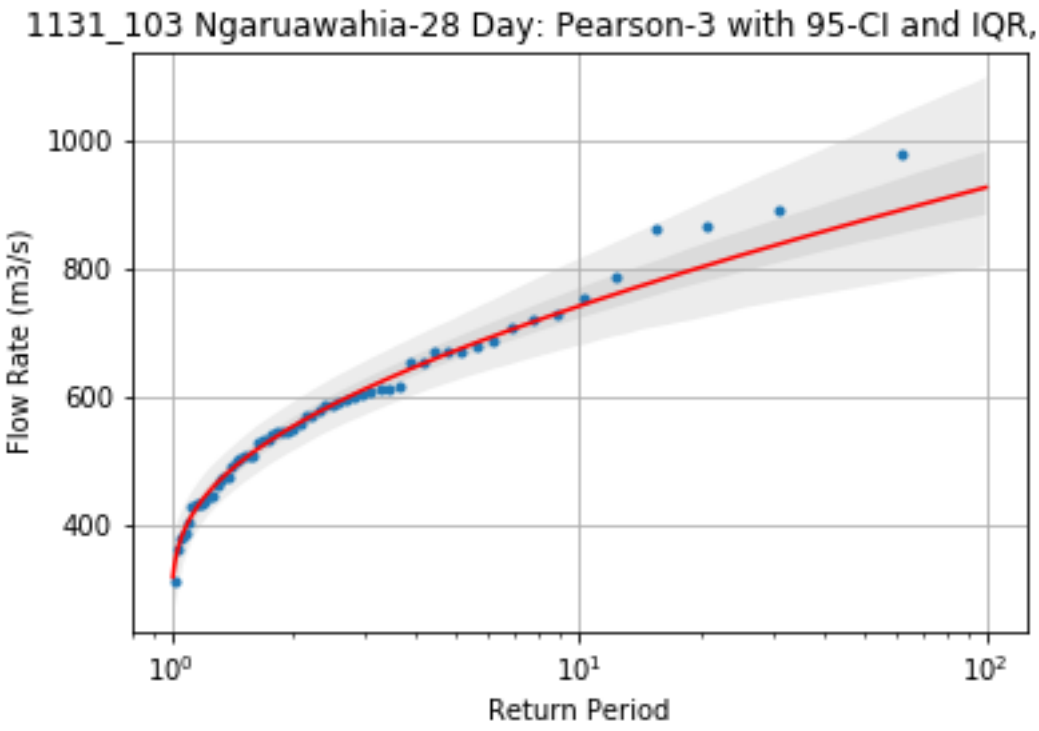

1131_103 Ngaruawahia-7 Day: LP-3 with 95-CI and IQR, n=61
Flow Rate (m3/s)
1400
1200
1000
800
600
400
10^0
10^1
10^2
Return Period

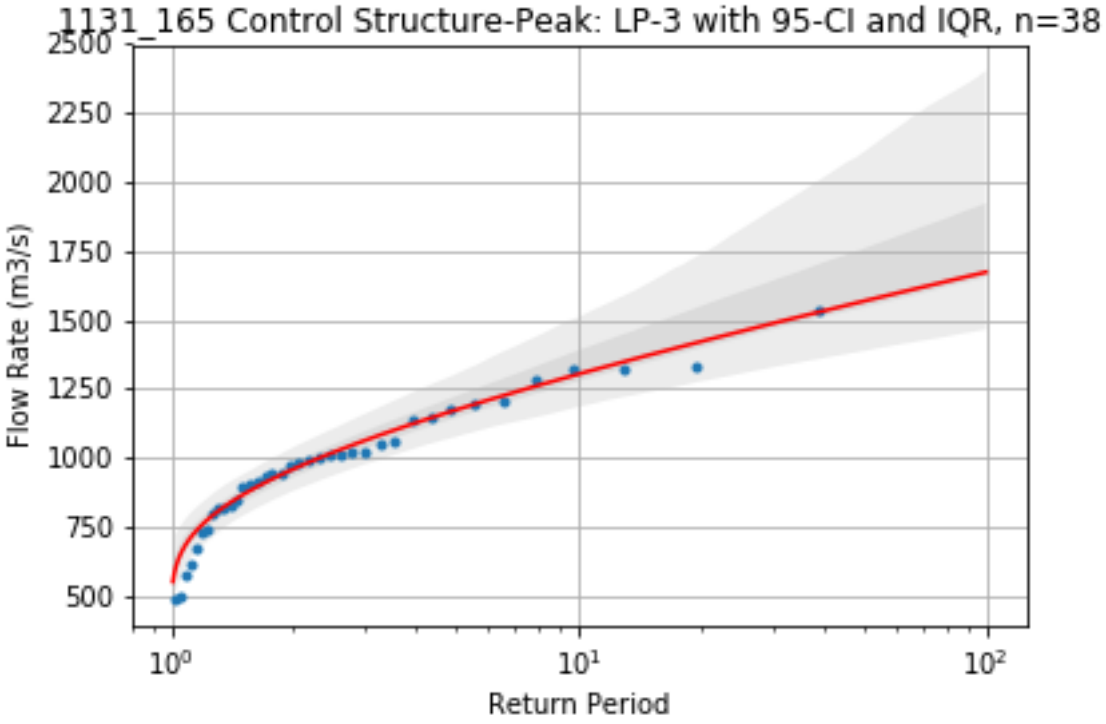

1131_103 Ngaruawahia-7 Day: Pearson-3 with 95-CI and IQR, n=61
Flow Rate (m3/s)
1400
1200
1000
800
600
400
10^0
10^1
10^2
Return Period

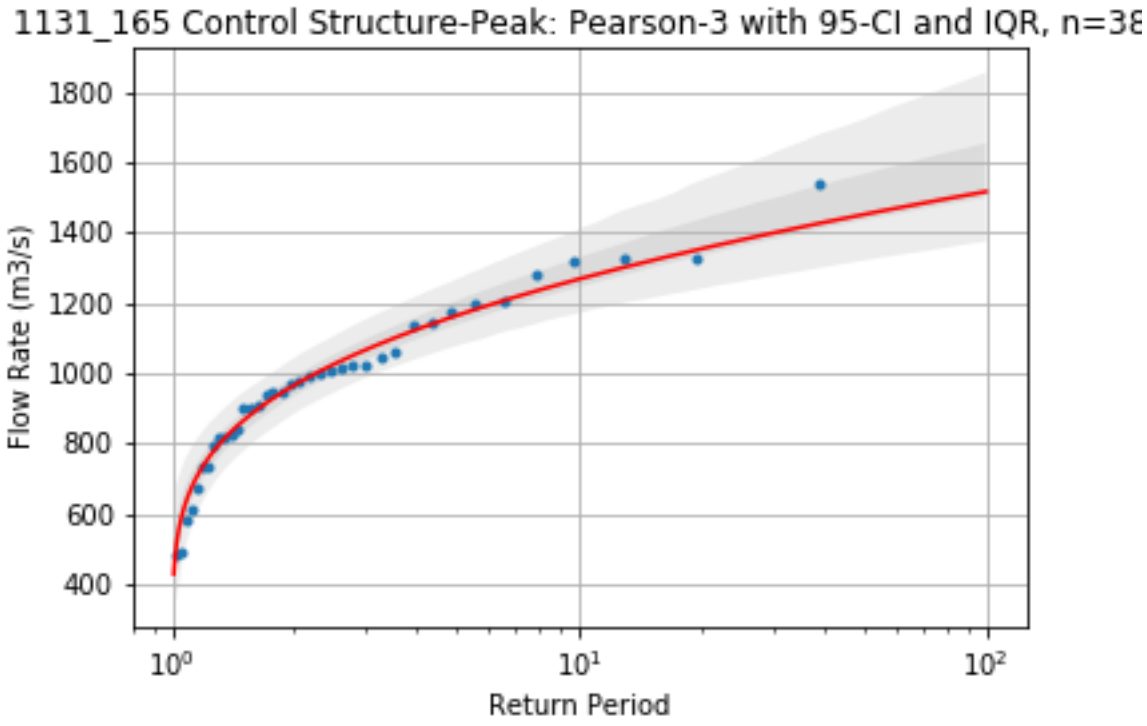

1131_103 Ngaruawahia-14 Day: LP-3 with 95-CI and IQR, n=61
Flow Rate (m3/s)
1400
1200
1000
800
600
400
10^0
10^1
10^2
Return Period

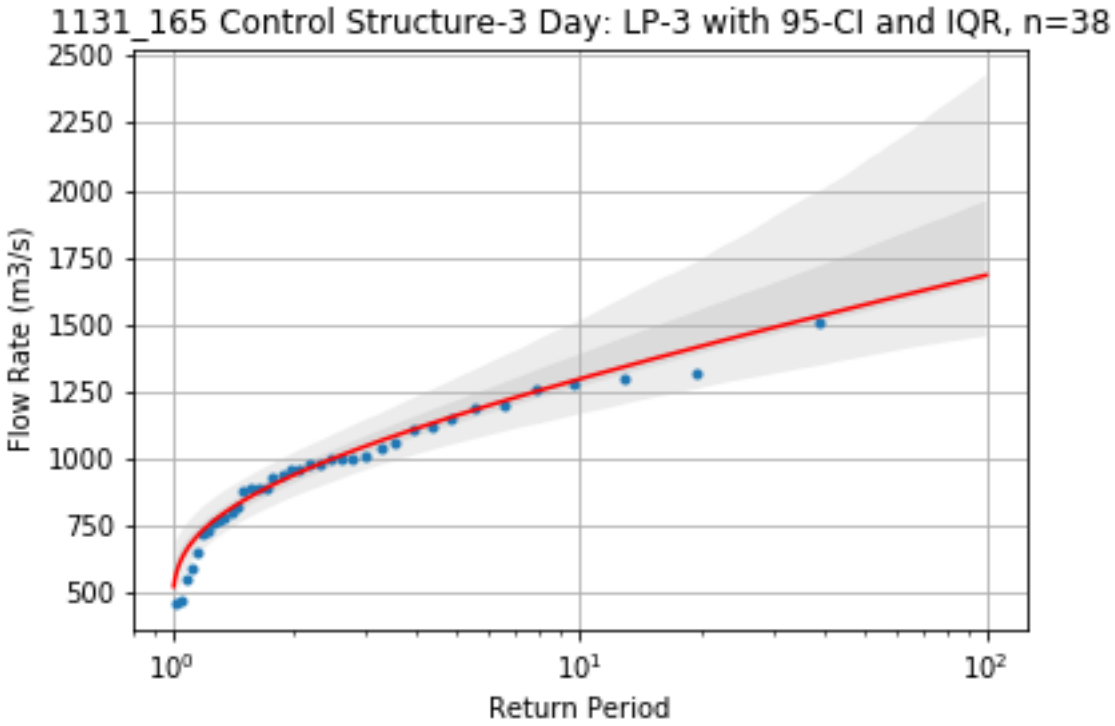

1131_103 Ngaruawahia-14 Day: Pearson-3 with 95-CI and IQR, n=61
Flow Rate (m3/s)
1200
1000
800
600
400
10^0
10^1
10^2
Return Period

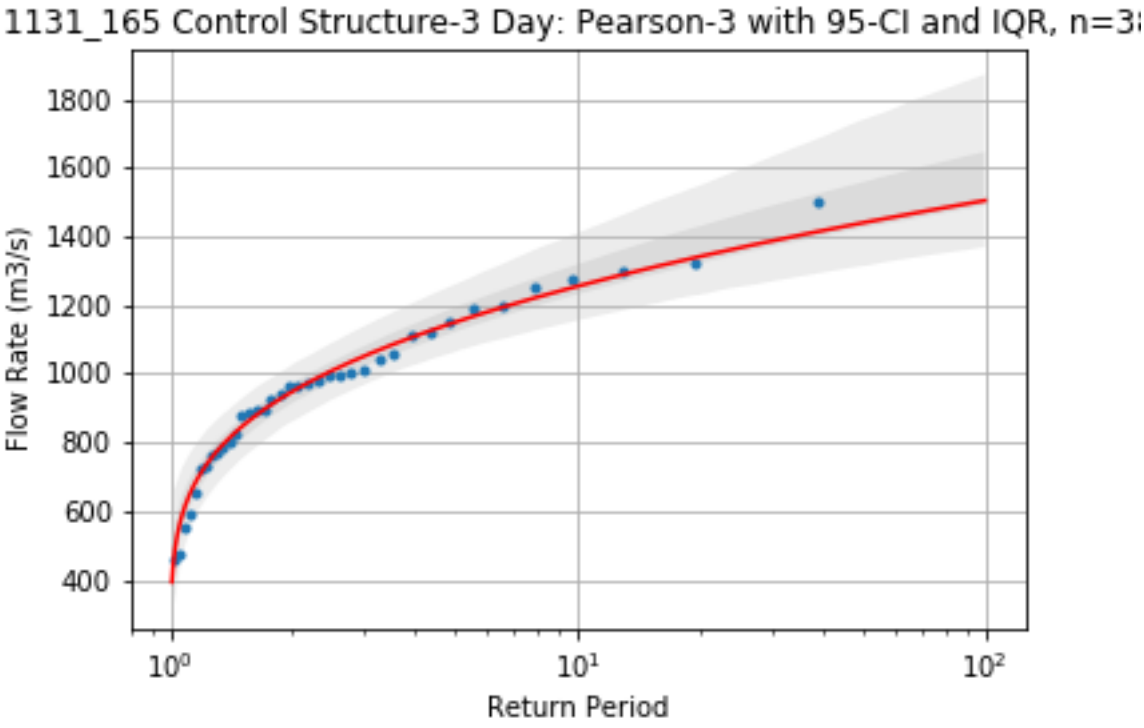

1131_103 Ngaruawahia-28 Day: LP-3 with 95-CI and IQR, n=61
Flow Rate (m3/s)
1200
1000
800
600
400
10^0
10^1
10^2
Return Period

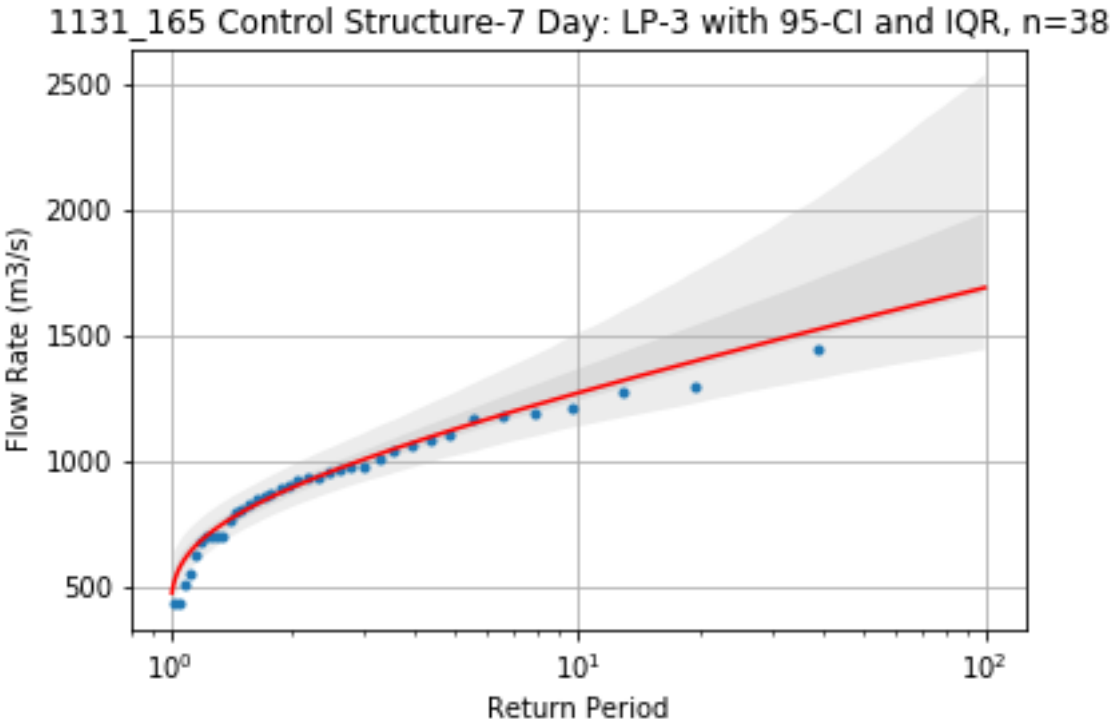

1131_103 Ngaruawahia-28 Day: Pearson-3 with 95-CI and IQR, n=61
Flow Rate (m3/s)
1000
800
600
400
10^0
10^1
10^2
Return Period

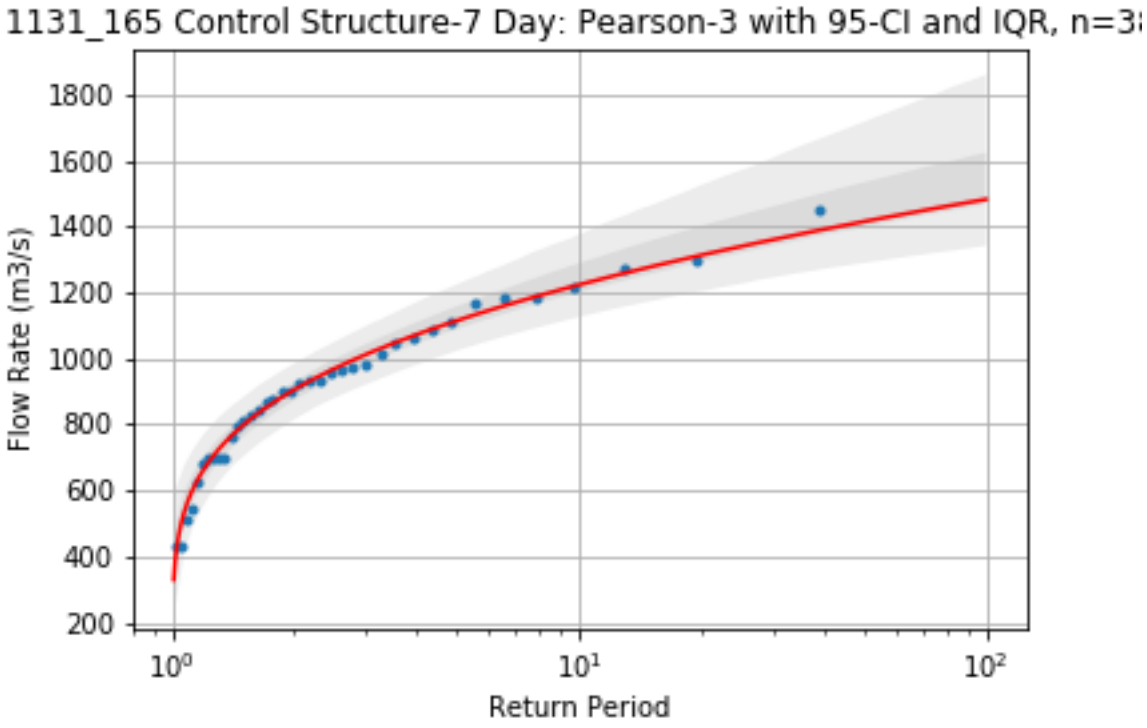

1131_165 Control Structure-Peak: LP-3 with 95-CI and IQR, n=38
Flow Rate (m3/s)
2500
2250
2000
1750
1500
1250
1000
750
500
10^0
10^1
10^2
Return Period

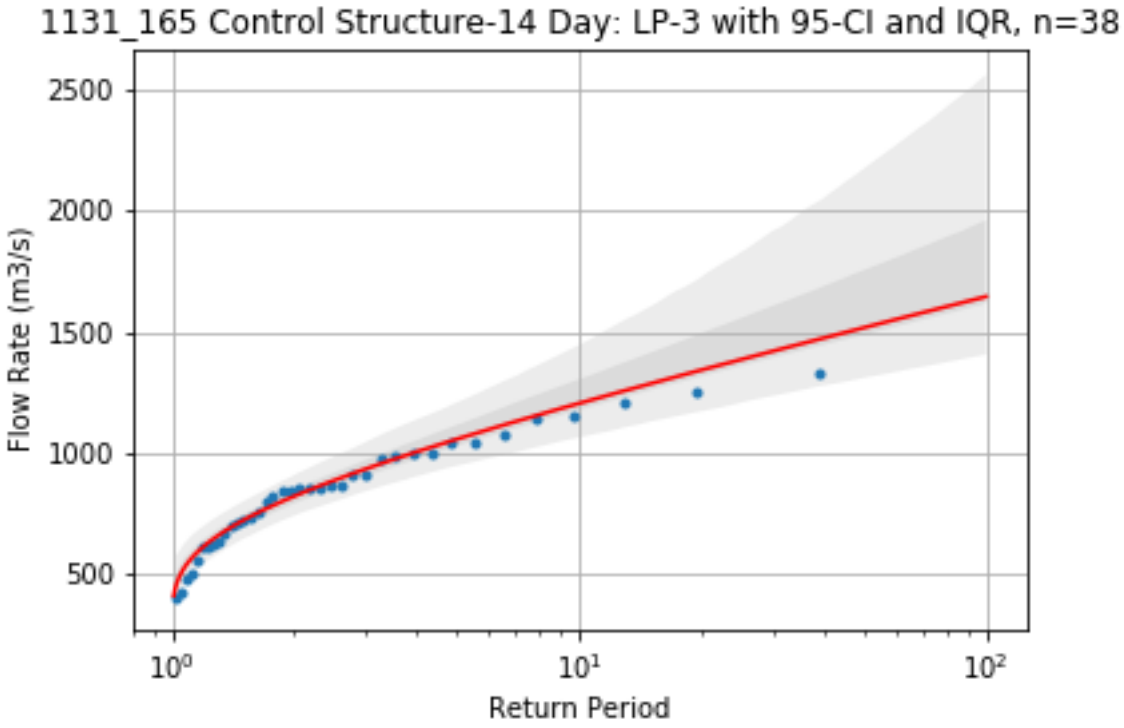

1131_165 Control Structure-Peak: Pearson-3 with 95-CI and IQR, n=38
Flow Rate (m3/s)
1800
1600
1400
1200
1000
800
600
400
10^0
10^1
10^2
Return Period

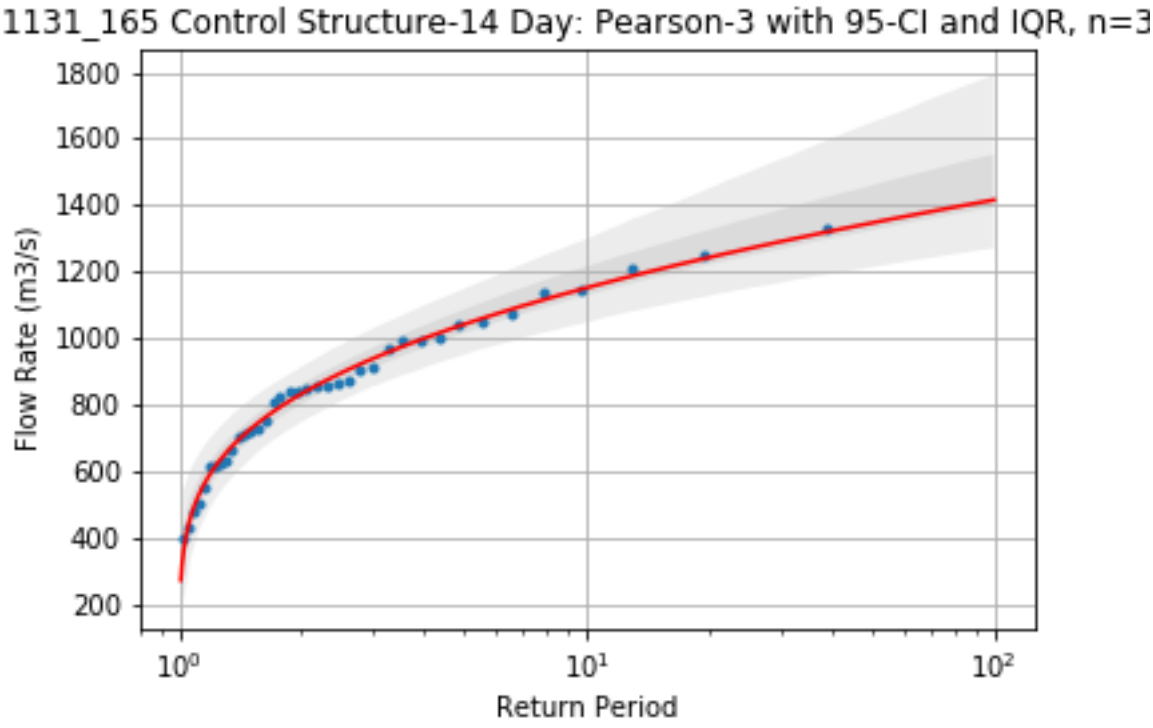

1131_165 Control Structure-3 Day: LP-3 with 95-CI and IQR, n=38
Flow Rate (m3/s)
2500
2250
2000
1750
1500
1250
1000
750
500
10^0
10^1
10^2
Return Period

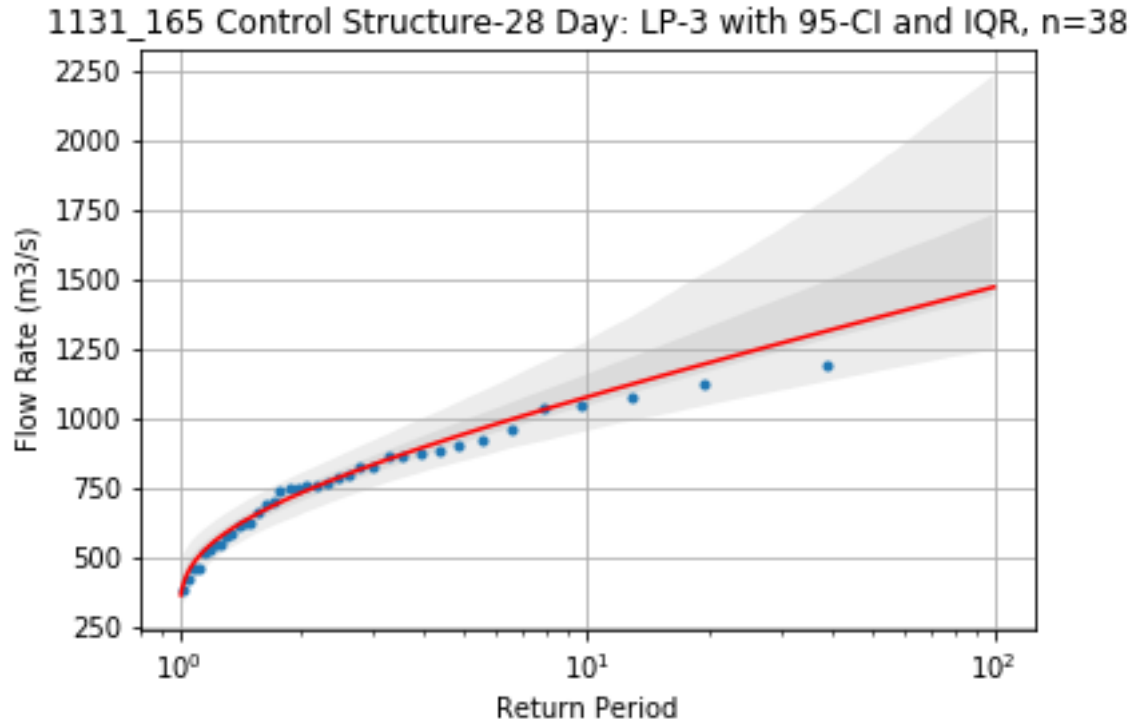

1131_165 Control Structure-3 Day: Pearson-3 with 95-CI and IQR, n=3
Flow Rate (m3/s)
1800
1600
1400
1200
1000
800
600
400
10^0
10^1
10^2
Return Period

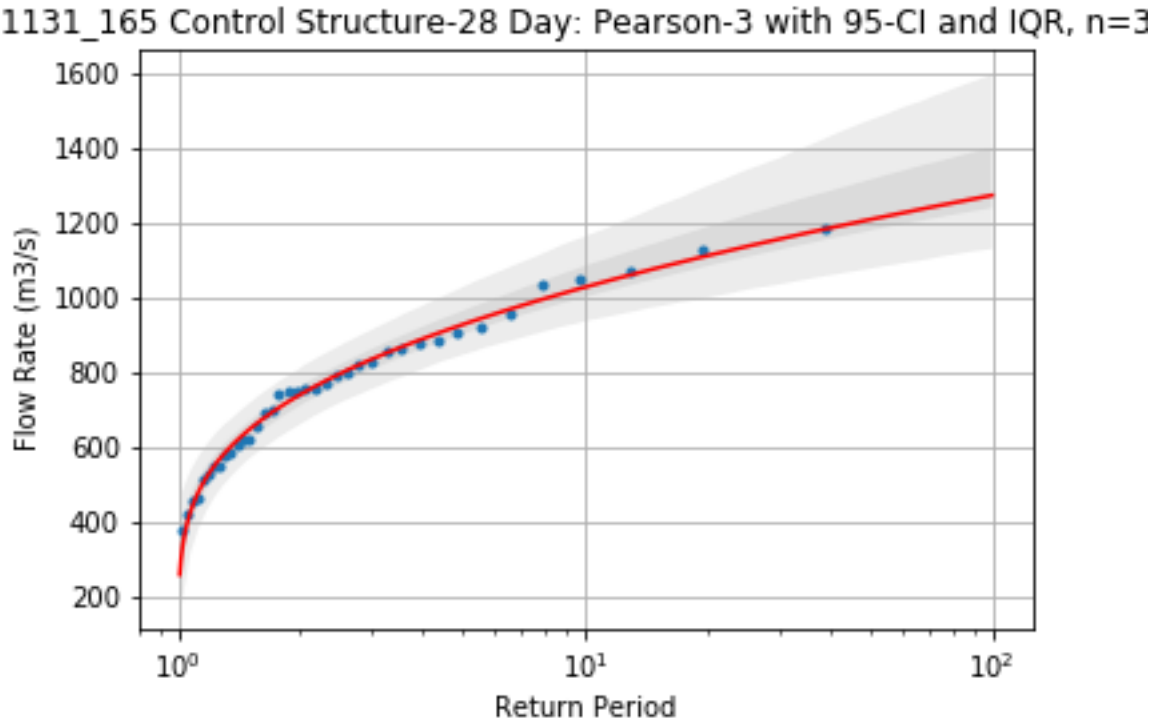

1131_165 Control Structure-7 Day: LP-3 with 95-CI and IQR, n=38
Flow Rate (m3/s)
2500
2000
1500
1000
500
10^0
10^1
10^2
Return Period

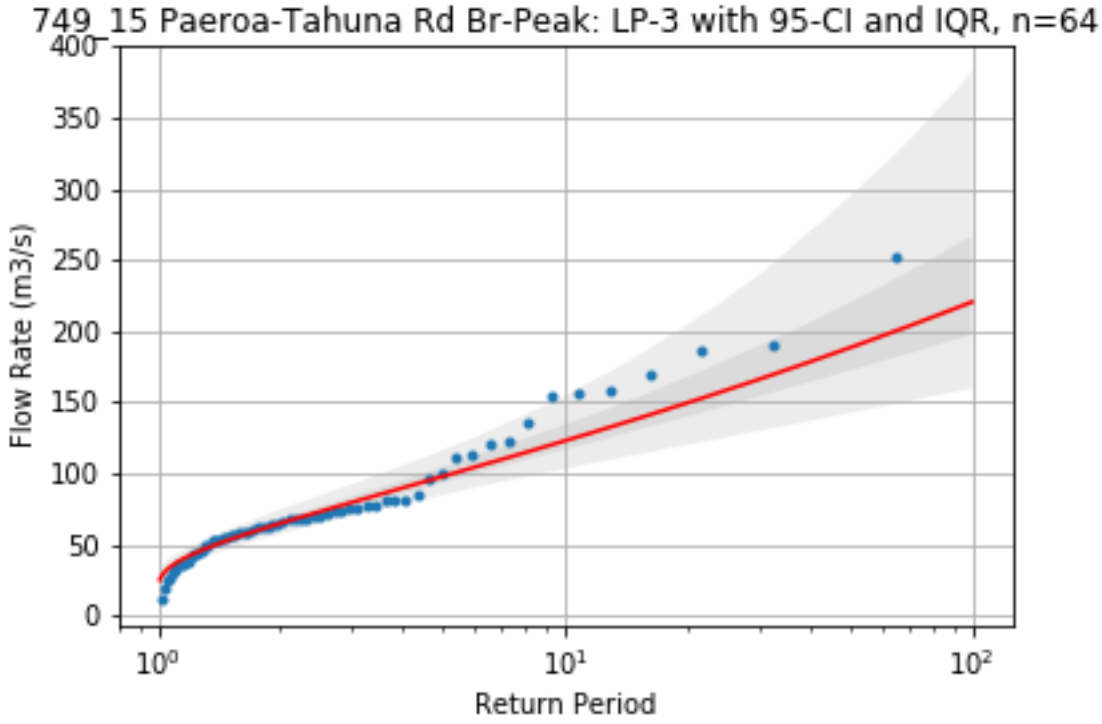

1131_165 Control Structure-7 Day: Pearson-3 with 95-CI and IQR, n=3
Flow Rate (m3/s)
1800
1600
1400
1200
1000
800
600
400
200
10^0
10^1
10^2
Return Period

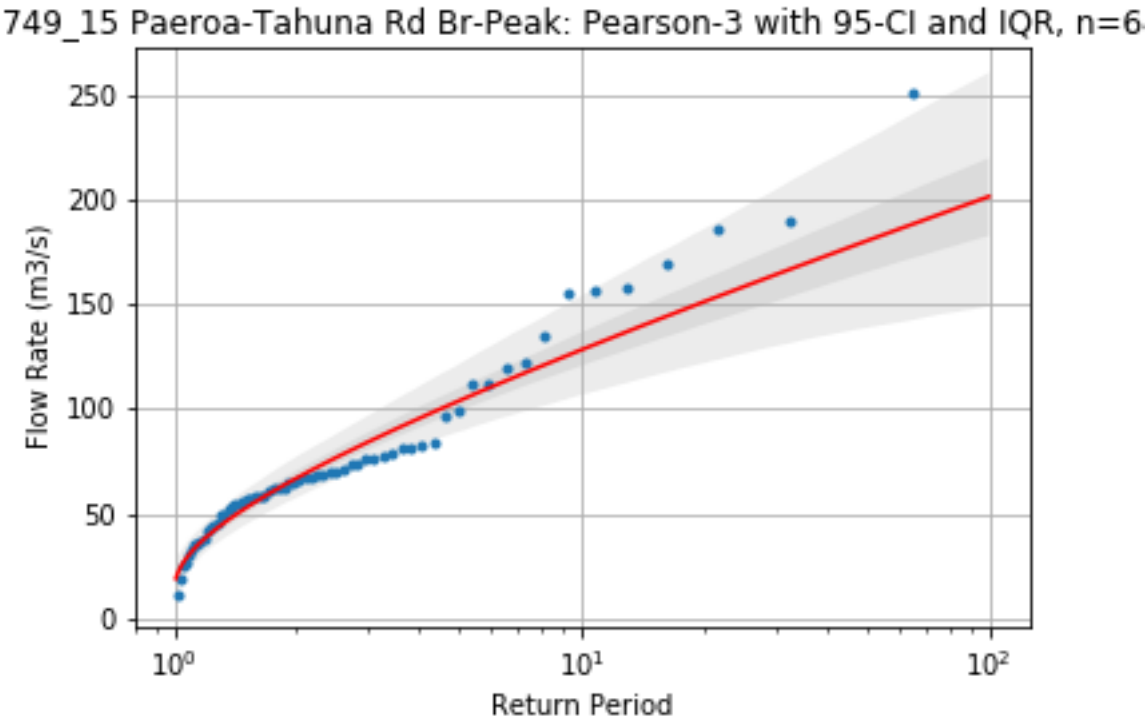

1131_165 Control Structure-14 Day: LP-3 with 95-CI and IQR, n=38
Flow Rate (m3/s)
2500
2000
1500
1000
500
10^0
10^1
10^2
Return Period

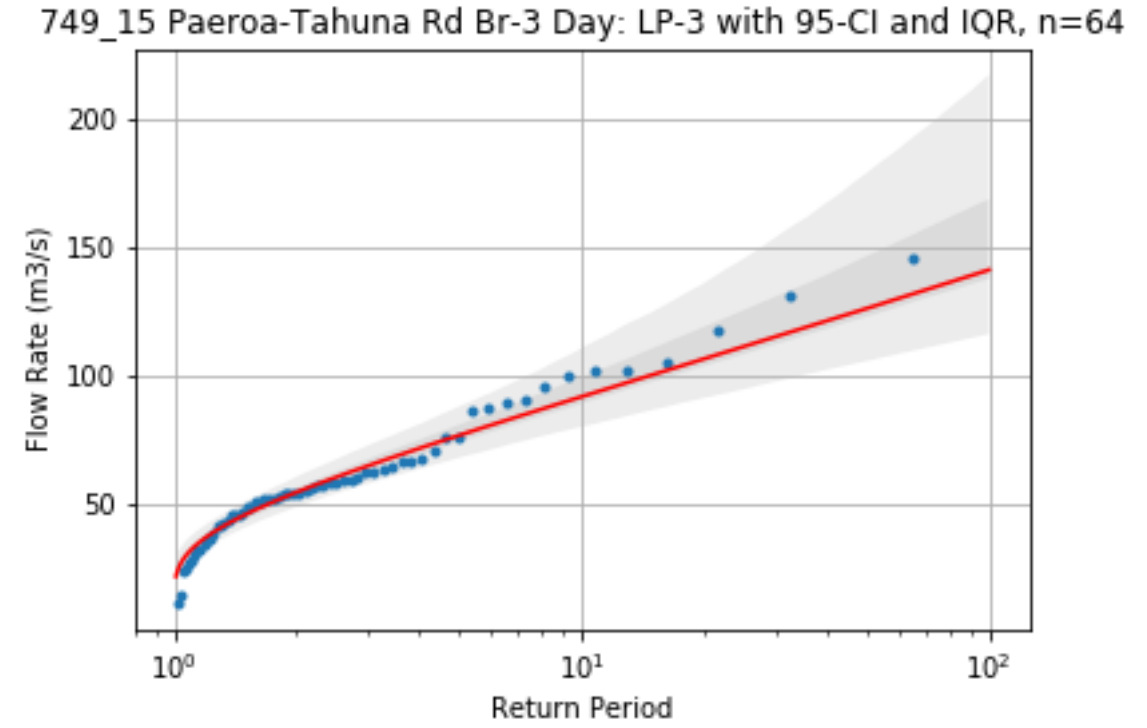

1131_165 Control Structure-14 Day: Pearson-3 with 95-CI and IQR, n=3
Flow Rate (m3/s)
1800
1600
1400
1200
1000
800
600
400
200
10^0
10^1
10^2
Return Period

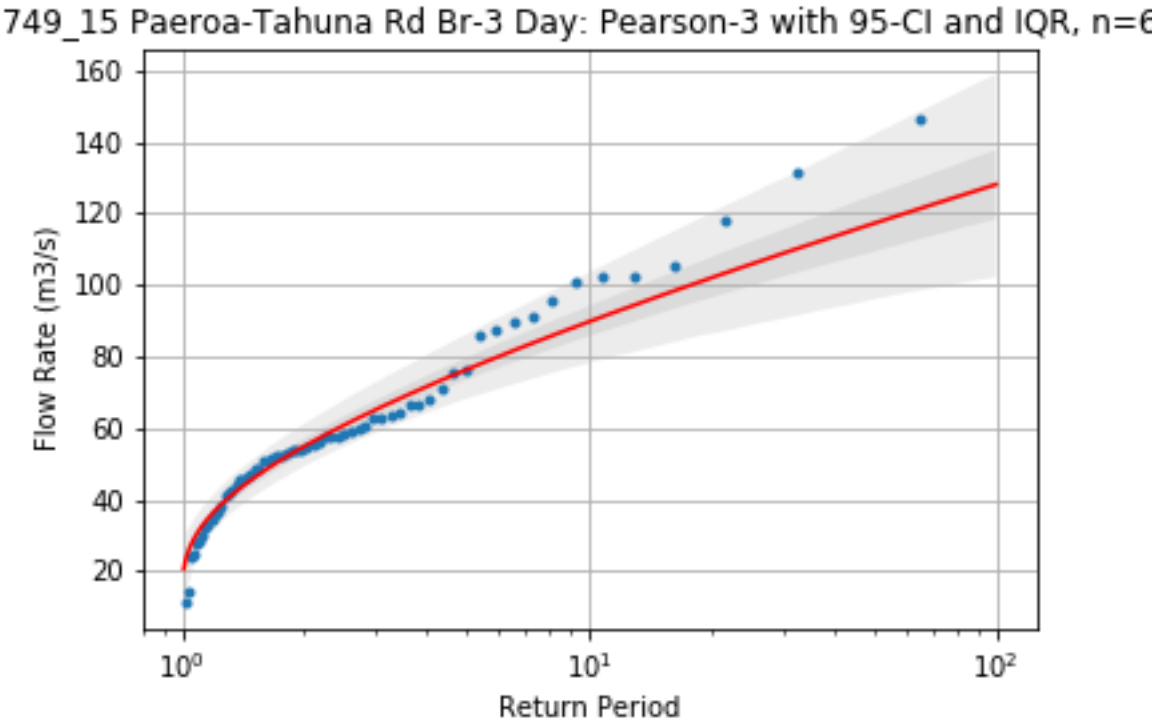

1131_165 Control Structure-28 Day: LP-3 with 95-CI and IQR, n=38
Flow Rate (m3/s)
2250
2000
1750
1500
1250
1000
750
500
250
10^0
10^1
10^2
Return Period

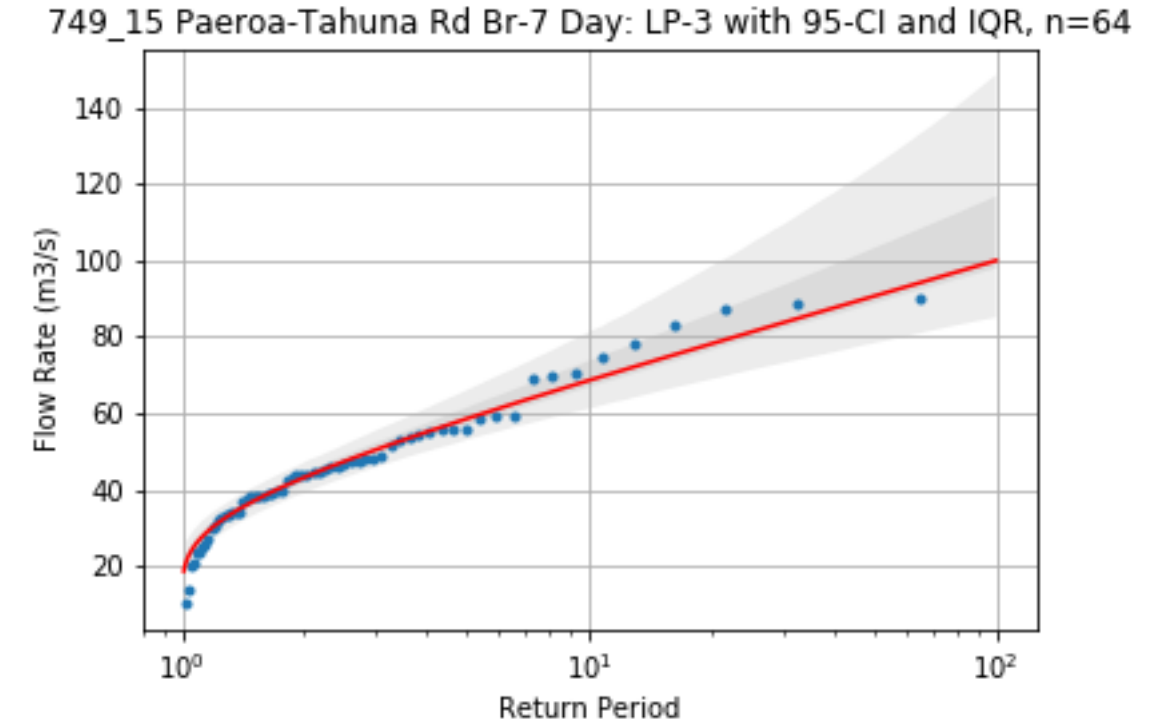

1131_165 Control Structure-28 Day: Pearson-3 with 95-CI and IQR, n=3
Flow Rate (m3/s)
1600
1400
1200
1000
800
600
400
200
10^0
10^1
10^2
Return Period

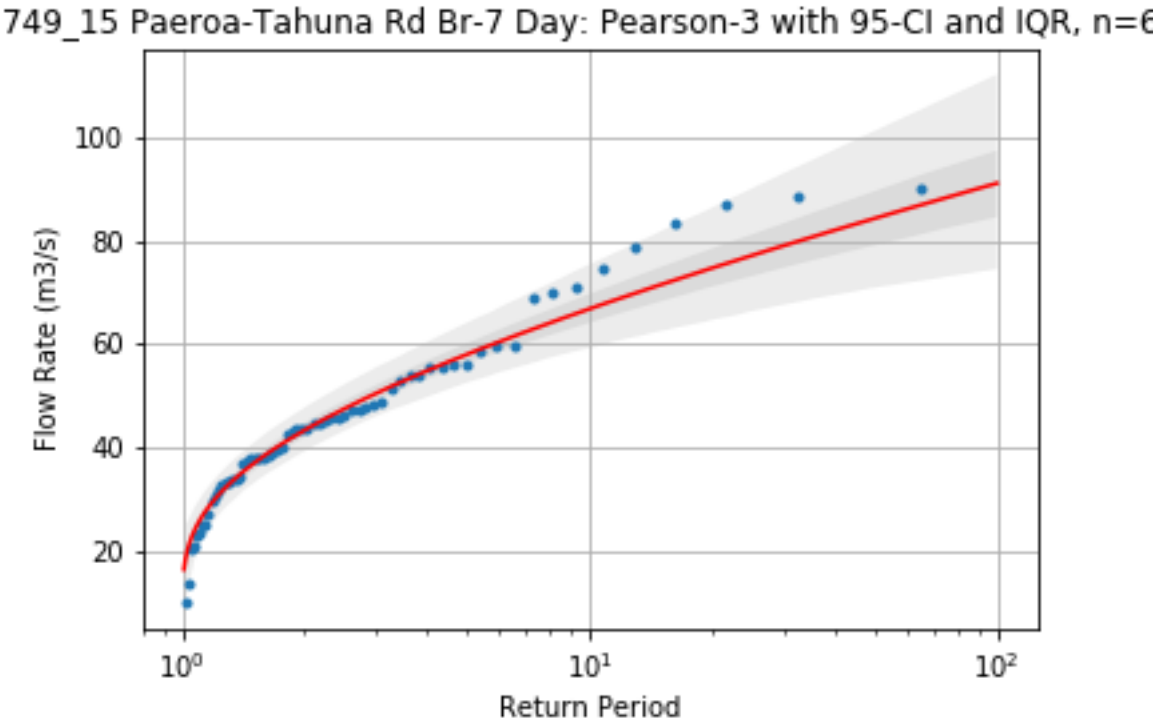

749_15 Paeroa-Tahuna Rd Br-Peak: LP-3 with 95-CI and IQR, n=64
Flow Rate (m3/s)
400
350
300
250
200
150
100
50
0
10^0
10^1
10^2
Return Period


749_15 Paeroa-Tahuna Rd Br-Peak: Pearson-3 with 95-CI and IQR, n=6
Flow Rate (m3/s)
250
200
150
100
50
0
10^0
10^1
10^2
Return Period


749_15 Paeroa-Tahuna Rd Br-3 Day: LP-3 with 95-CI and IQR, n=64
Flow Rate (m3/s)
200
150
100
50
10^0
10^1
10^2
Return Period


749_15 Paeroa-Tahuna Rd Br-3 Day: Pearson-3 with 95-CI and IQR, n=6
Flow Rate (m3/s)
160
140
120
100
80
60
40
20
10^0
10^1
10^2
Return Period


749_15 Paeroa-Tahuna Rd Br-7 Day: LP-3 with 95-CI and IQR, n=64
Flow Rate (m3/s)
140
120
100
80
60
40
20
10^0
10^1
10^2
Return Period


749_15 Paeroa-Tahuna Rd Br-7 Day: Pearson-3 with 95-CI and IQR, n=6
Flow Rate (m3/s)
100
80
60
40
20
10^0
10^1
10^2
Return Period

Appendix 6: Monthly river levels compared to March/April 2017

A6.1 Waihou/Piako Zone

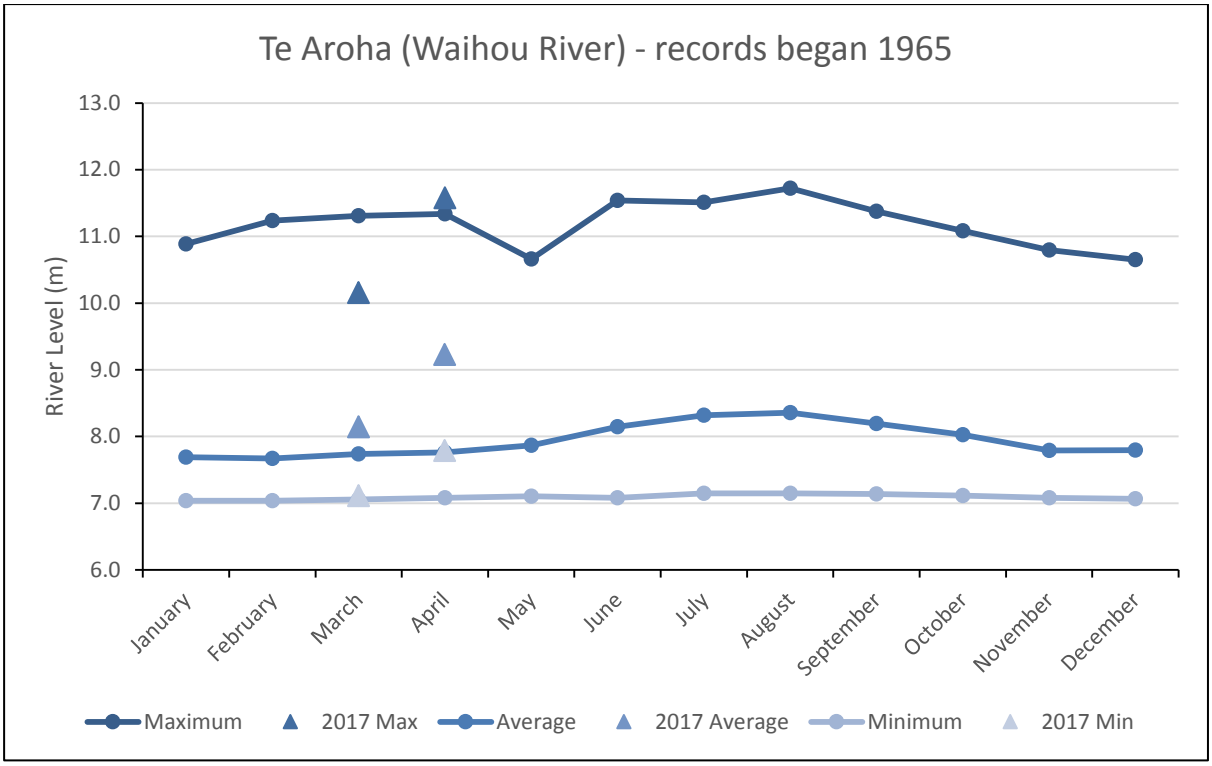


Figure 36: Maximum and minimum river level values recorded at Te Aroha (Waihou River) during each month over historic records, with monthly averages. March/April 2017 maximums, average, and minimum river levels for comparison.

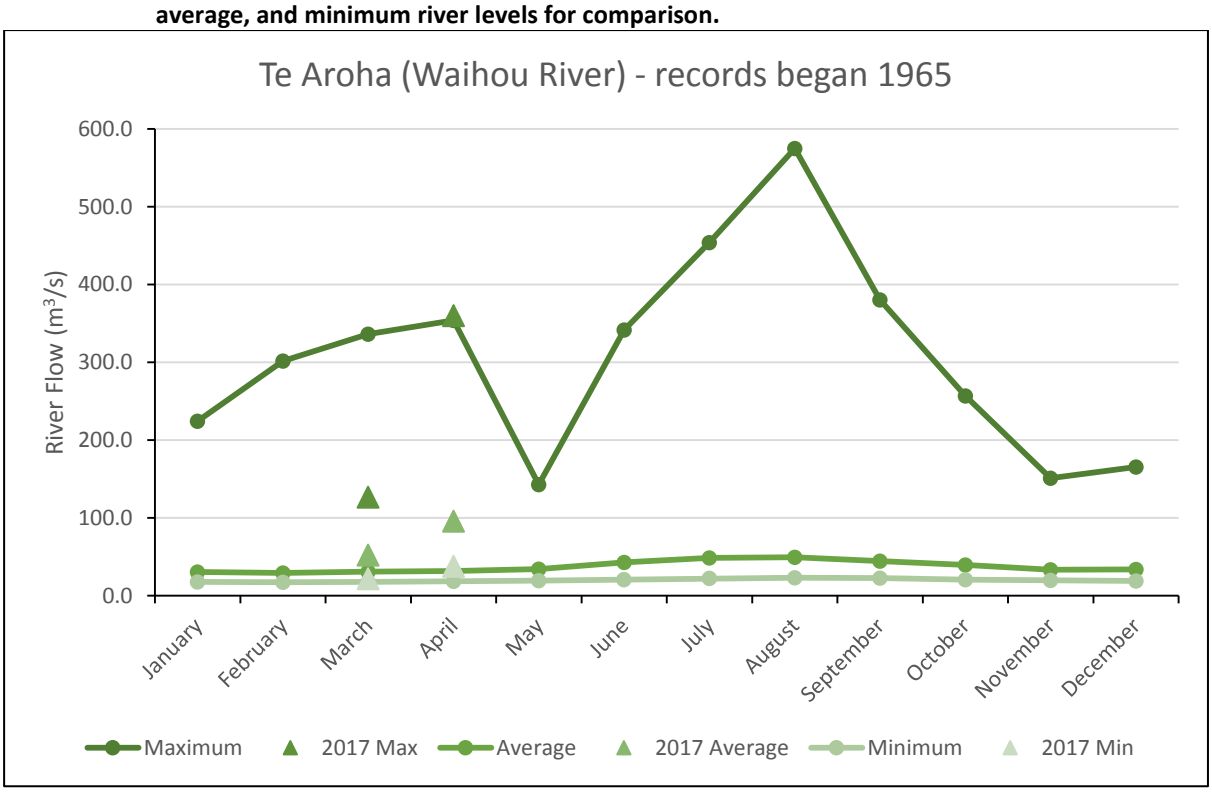


Figure 37: Maximum and minimum river flow values recorded at Te Aroha (Waihou River) during each month over historic records, with monthly averages. March/April 2017 maximums, average, and minimum river flows for comparison.

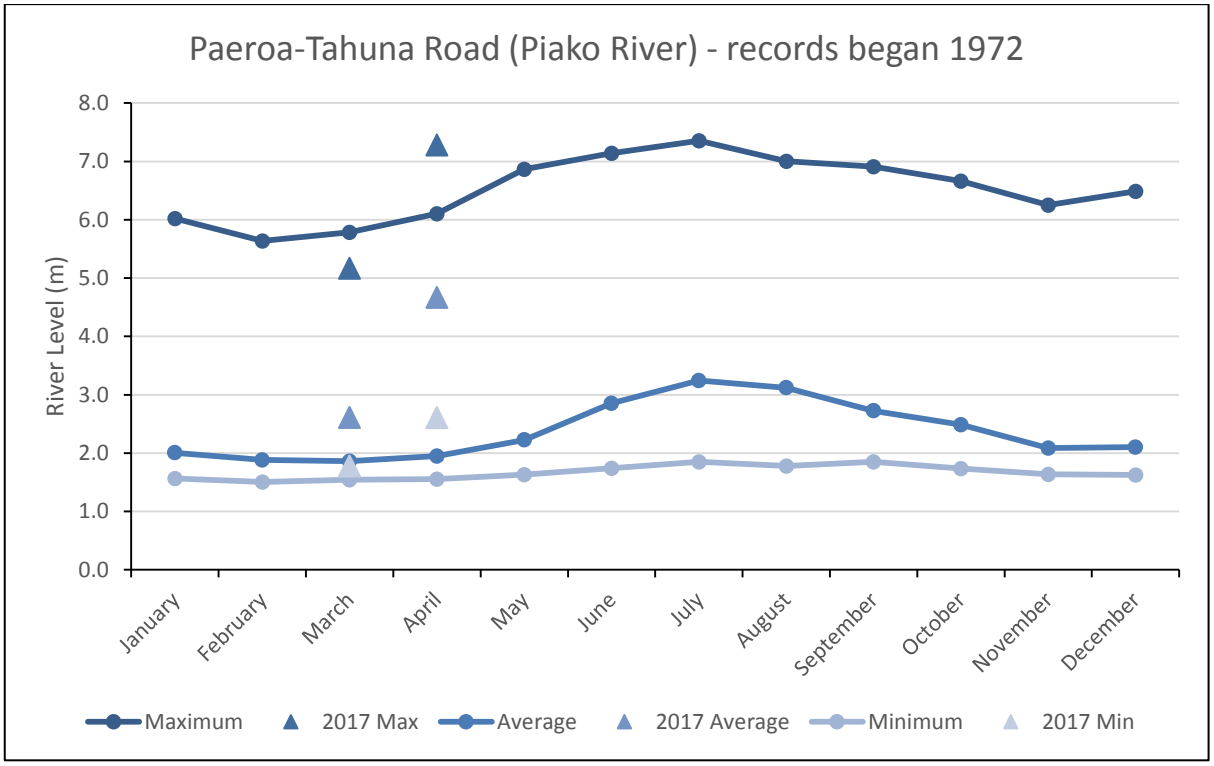


Figure 38: Maximum and minimum river level values recorded at Paeroa-Tahuna Road (Piako River) during each month over historic records, with monthly averages. March/April 2017 maximums, average, and minimum river levels for comparison.

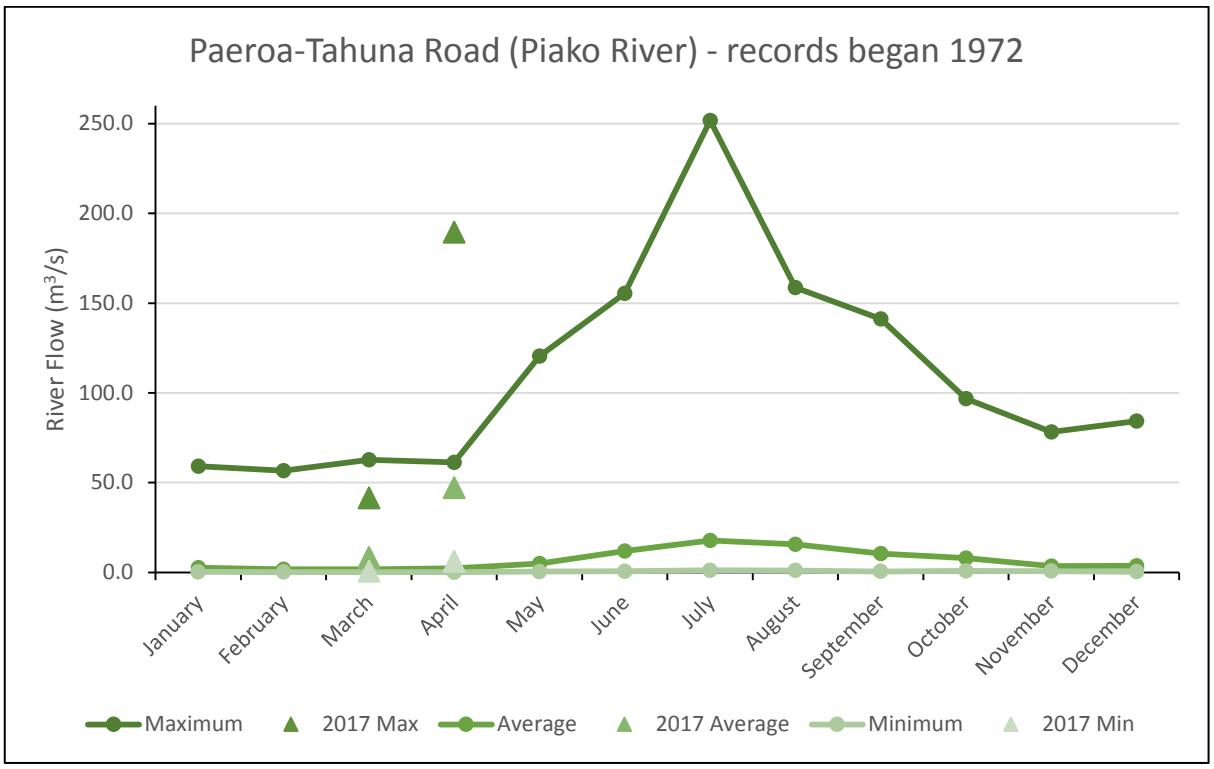


Figure 39: Maximum and minimum river flow values recorded at Paeroa-Tahuna Road (Piako River) during each month over historic records, with monthly averages. March/April 2017 maximums, average, and minimum river flows for comparison.

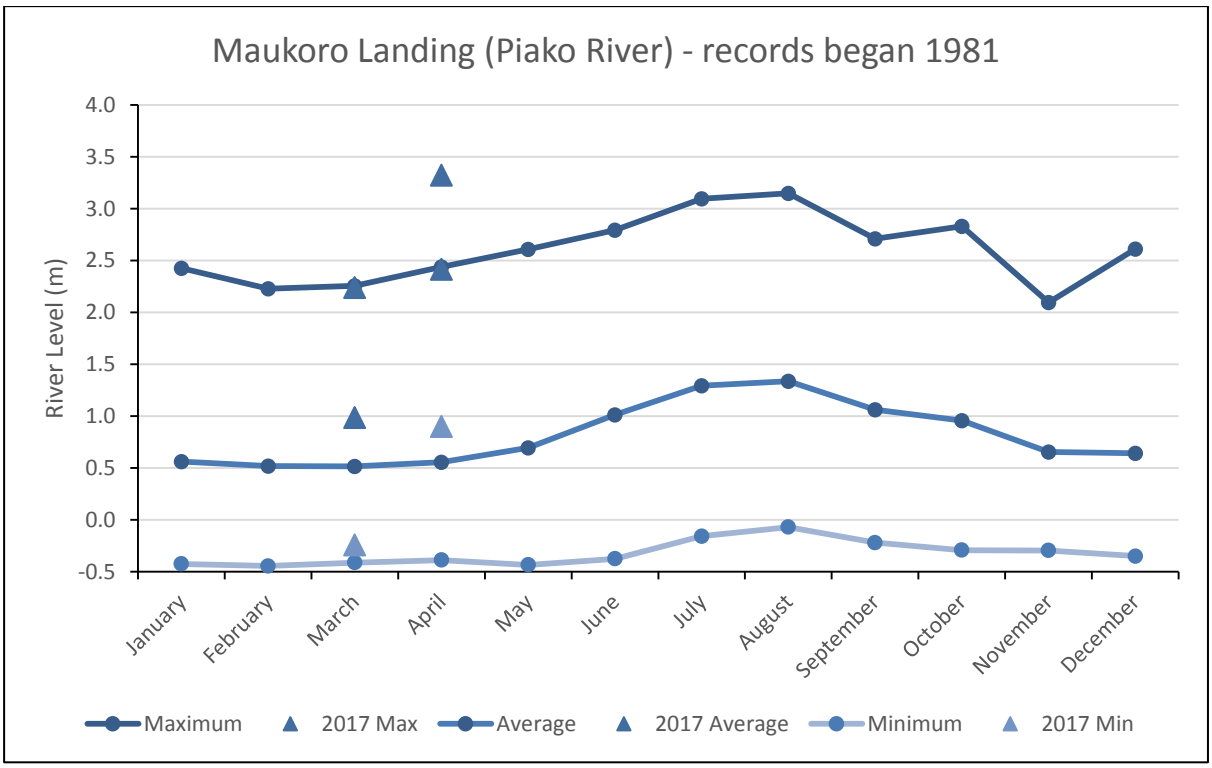


Figure 40: Maximum and minimum river level values recorded at Maukoro Landing (Piako River) during each month over historic records, with monthly averages. March/April 2017 maximums, average, and minimum river levels for comparison.

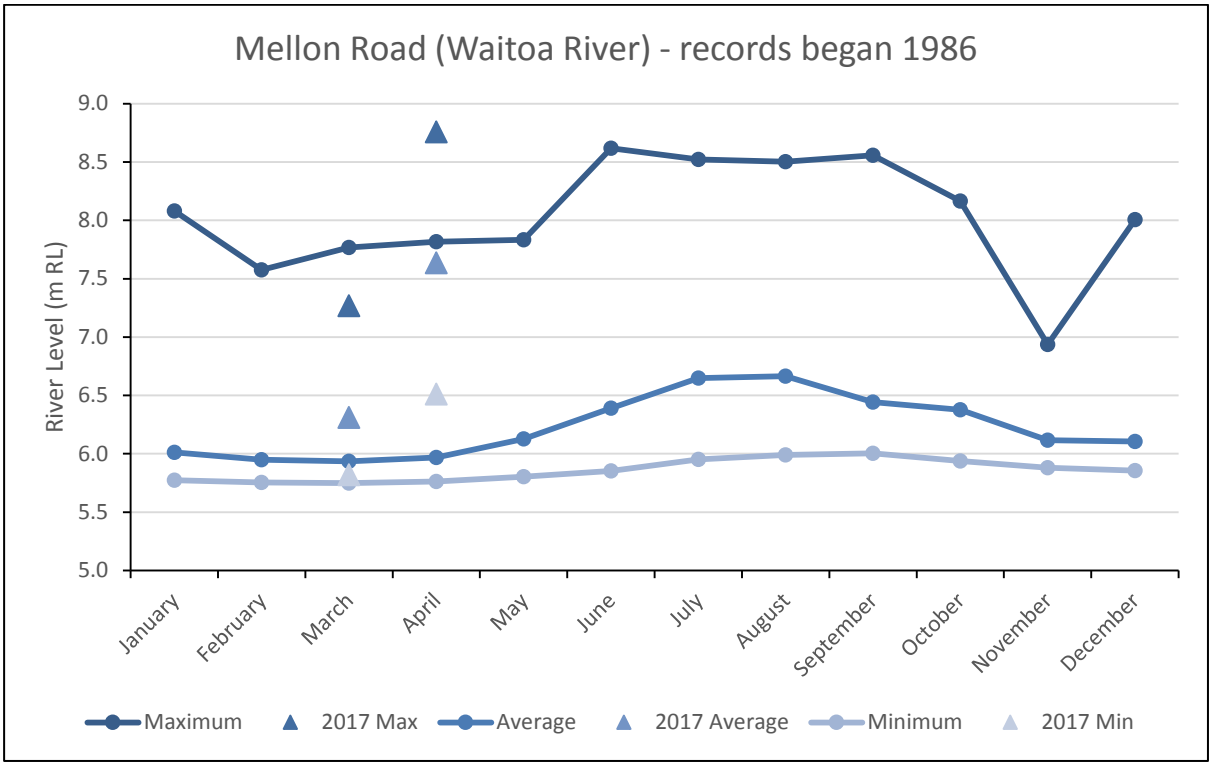


Figure 41: Maximum and minimum river level values recorded at Mellon Road (Waitoa River) during each month over historic records, with monthly averages. March/April 2017 maximums, average, and minimum river levels for comparison.

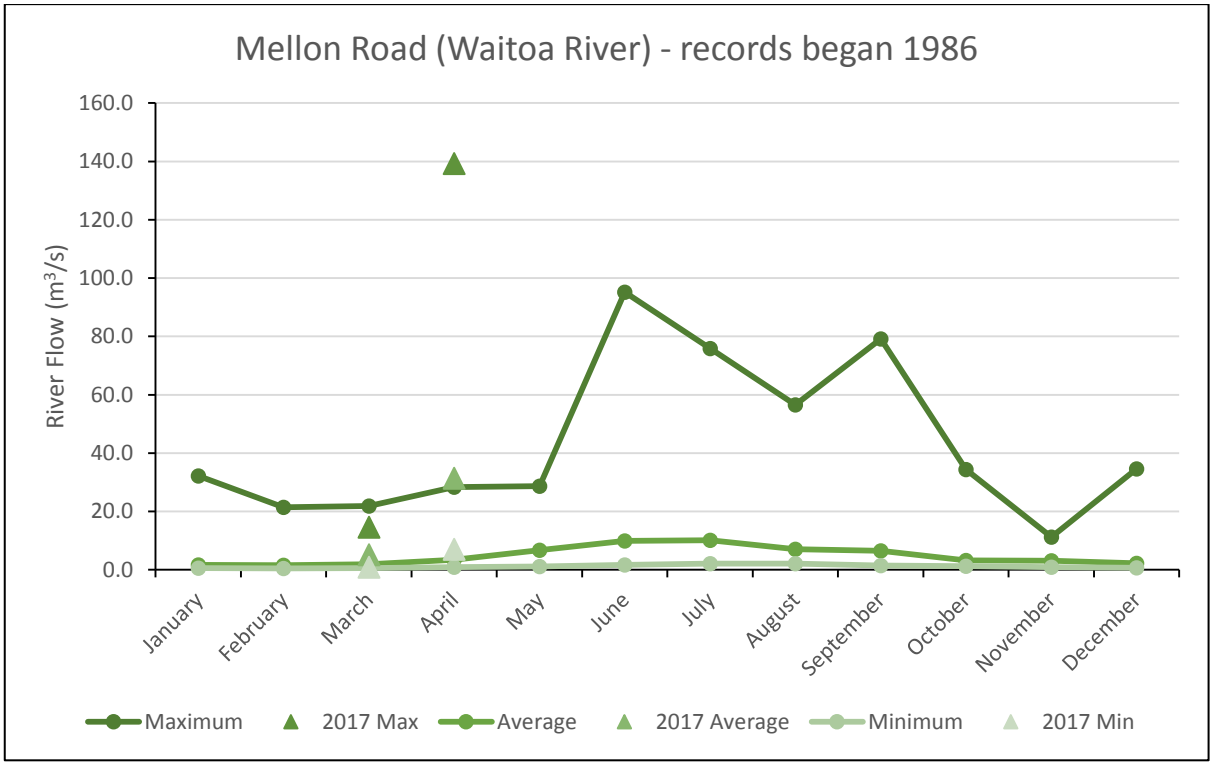


Figure 42: Maximum and minimum river flow values recorded at Mellon Road (Waitoa River) during each month over historic records, with monthly averages. March/April 2017 maximums, average, and minimum river flows for comparison.

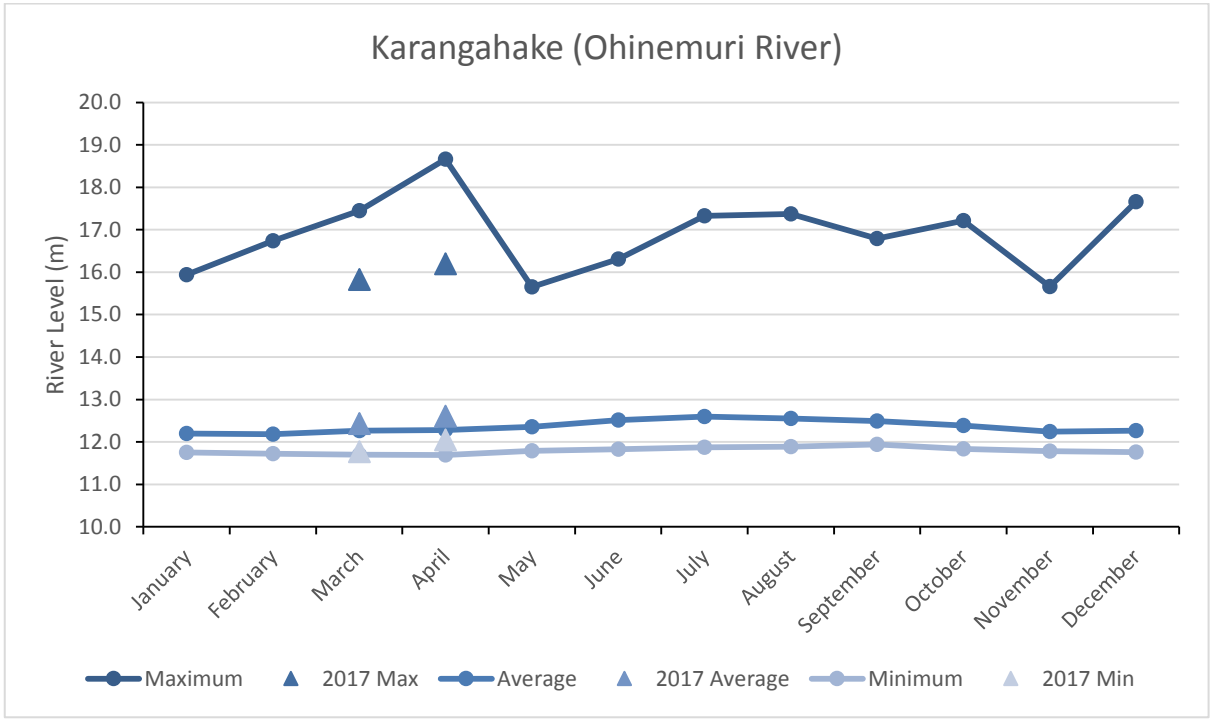


Figure 43: Maximum and minimum river level values recorded at Karangahake (Ohinemuri River) during each month over historic records, with monthly averages. March/April 2017 maximums, average, and minimum river levels for comparison.

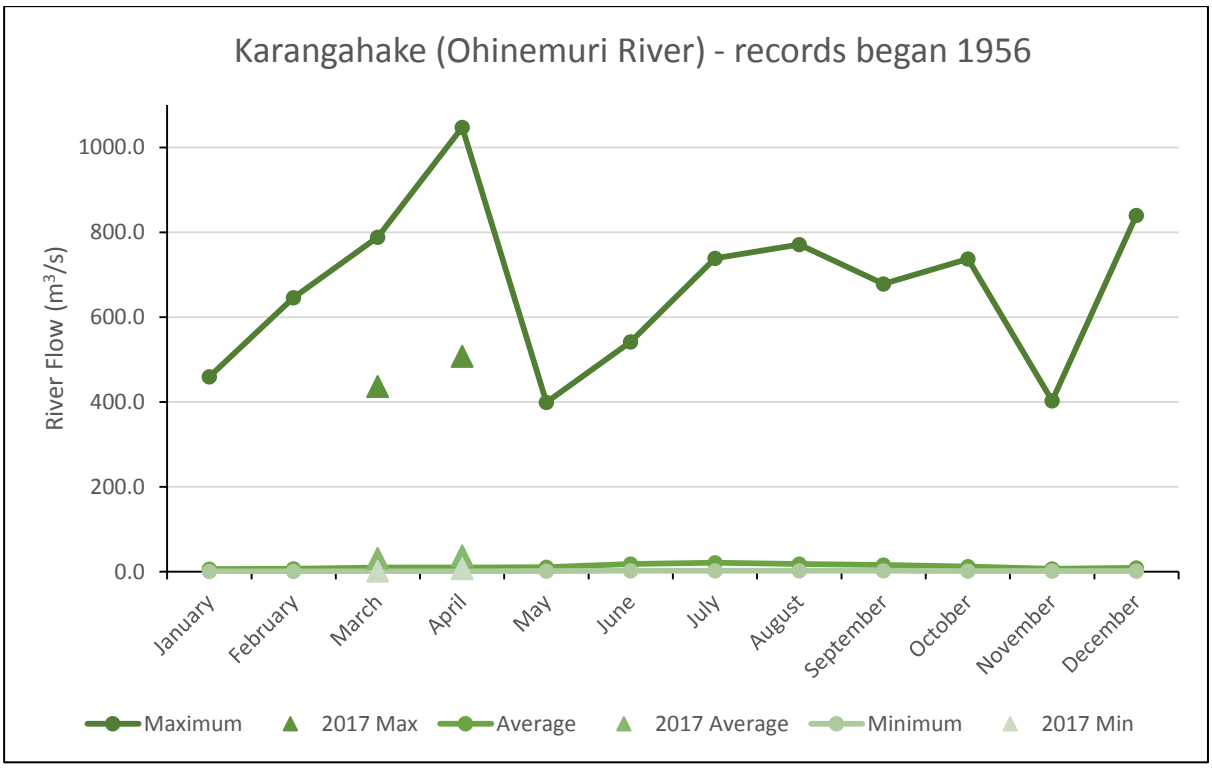


Figure 44: Maximum and minimum river flow values recorded at Karangahake (Ohinemuri River) during each month over historic records, with monthly averages. March/April 2017 maximums, average, and minimum river flows for comparison.

A6.2 Lower Waikato Zone

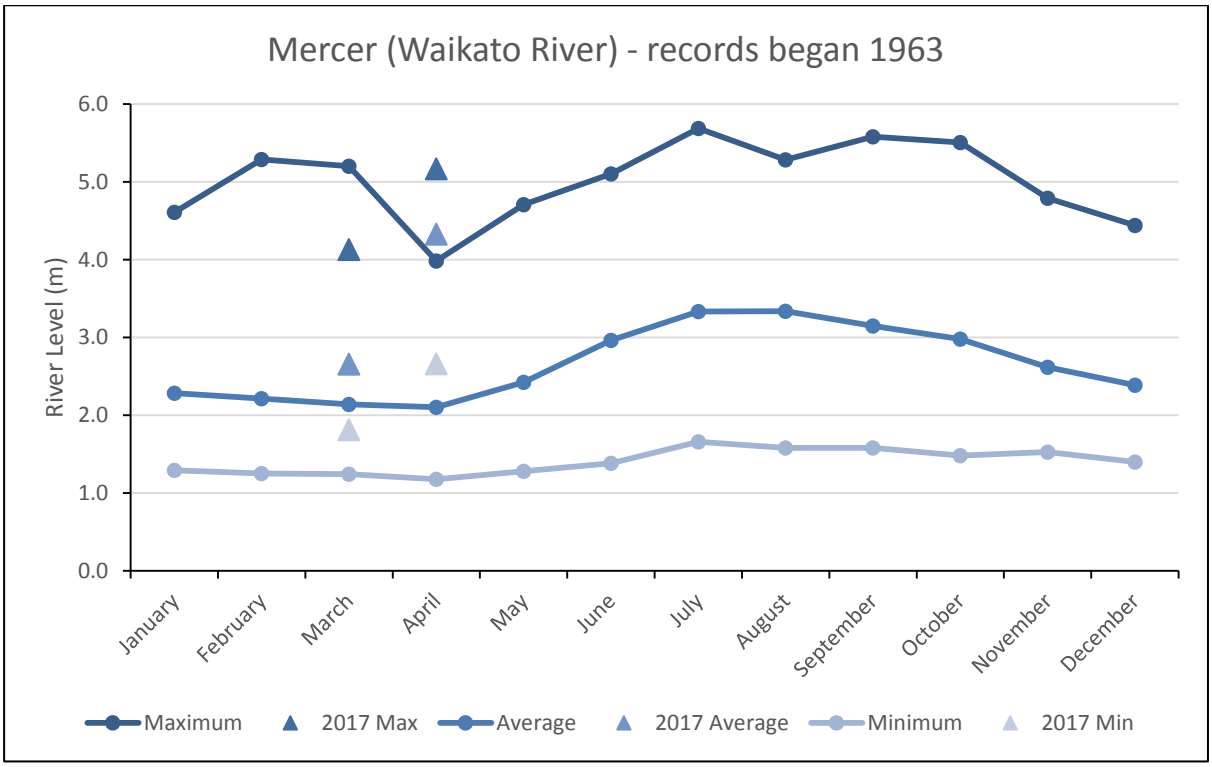


Figure 45: Maximum and minimum river level values recorded at Mercer (Waikato River) during each month over historic records, with monthly averages. March/April 2017 maximums, average, and minimum river levels for comparison.

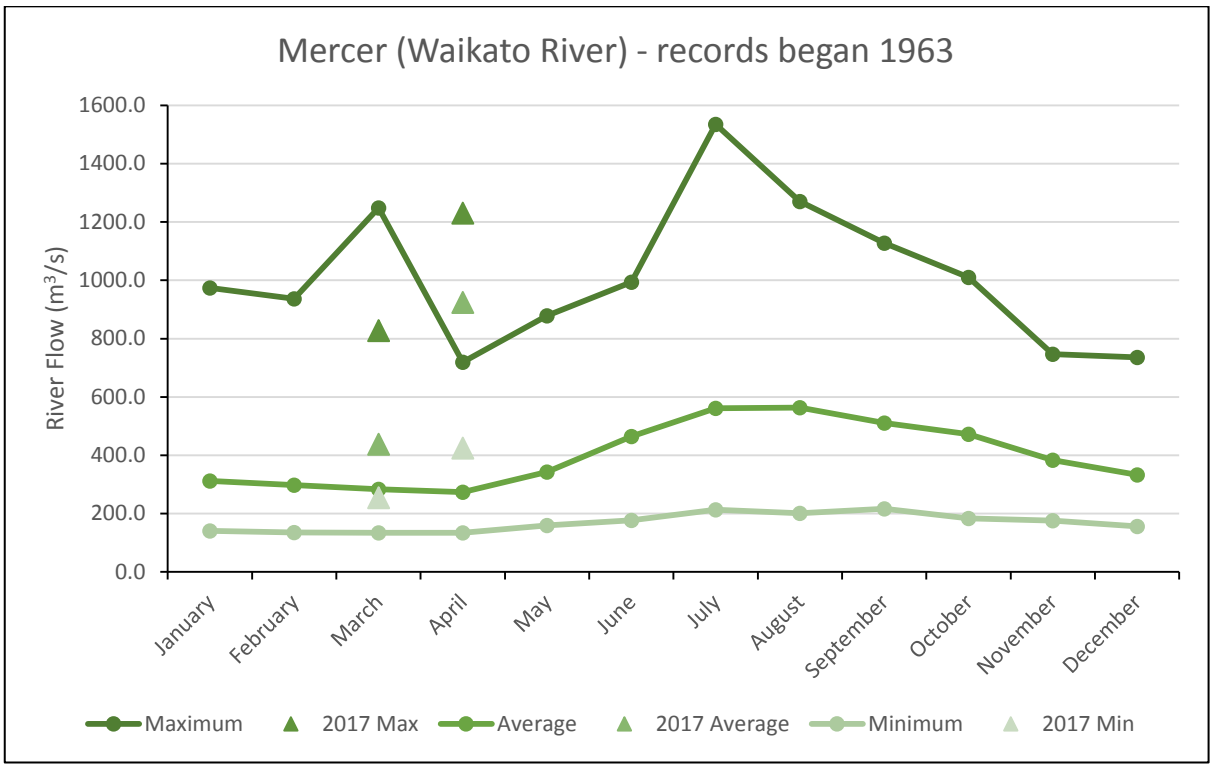


Figure 46: Maximum and minimum river flow values recorded at Mercer (Waikato River) during each month over historic records, with monthly averages. March/April 2017 maximums, average, and minimum river flows for comparison.

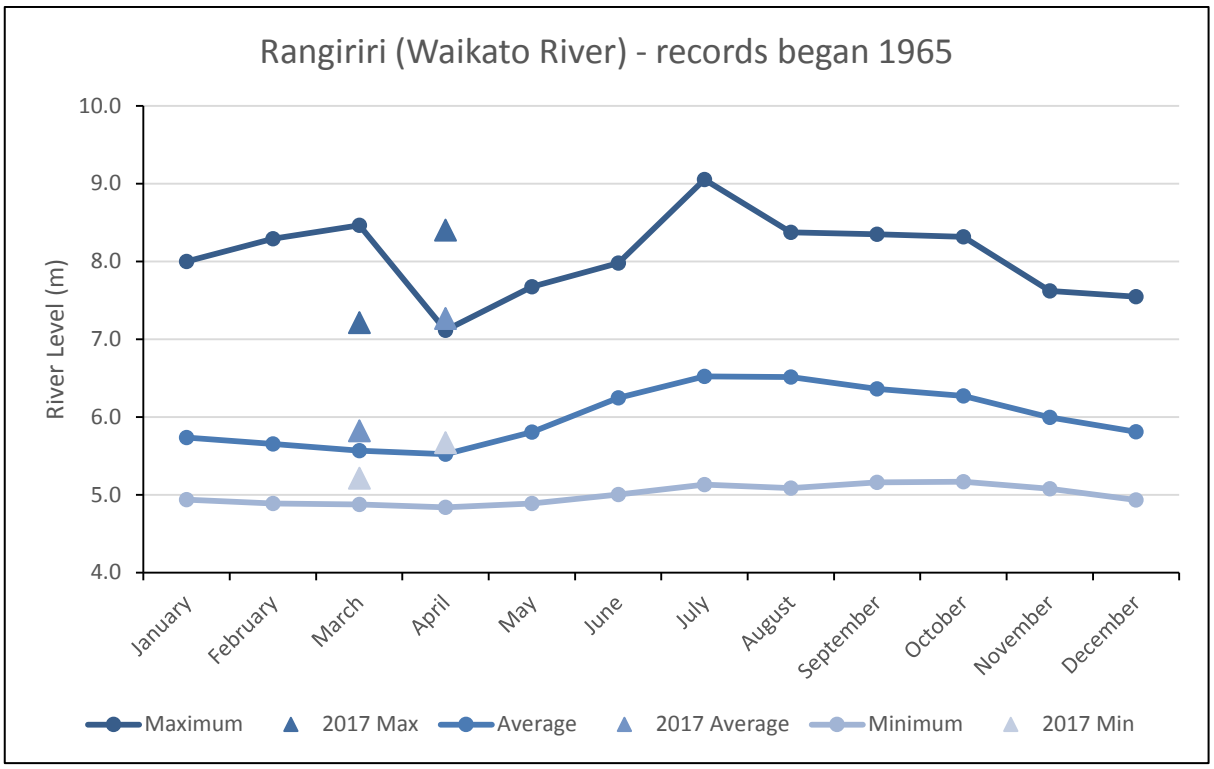


Figure 47: Maximum and minimum river level values recorded at Rangiriri (Waikato River) during each month over historic records, with monthly averages. March/April 2017 maximums, average, and minimum river levels for comparison.

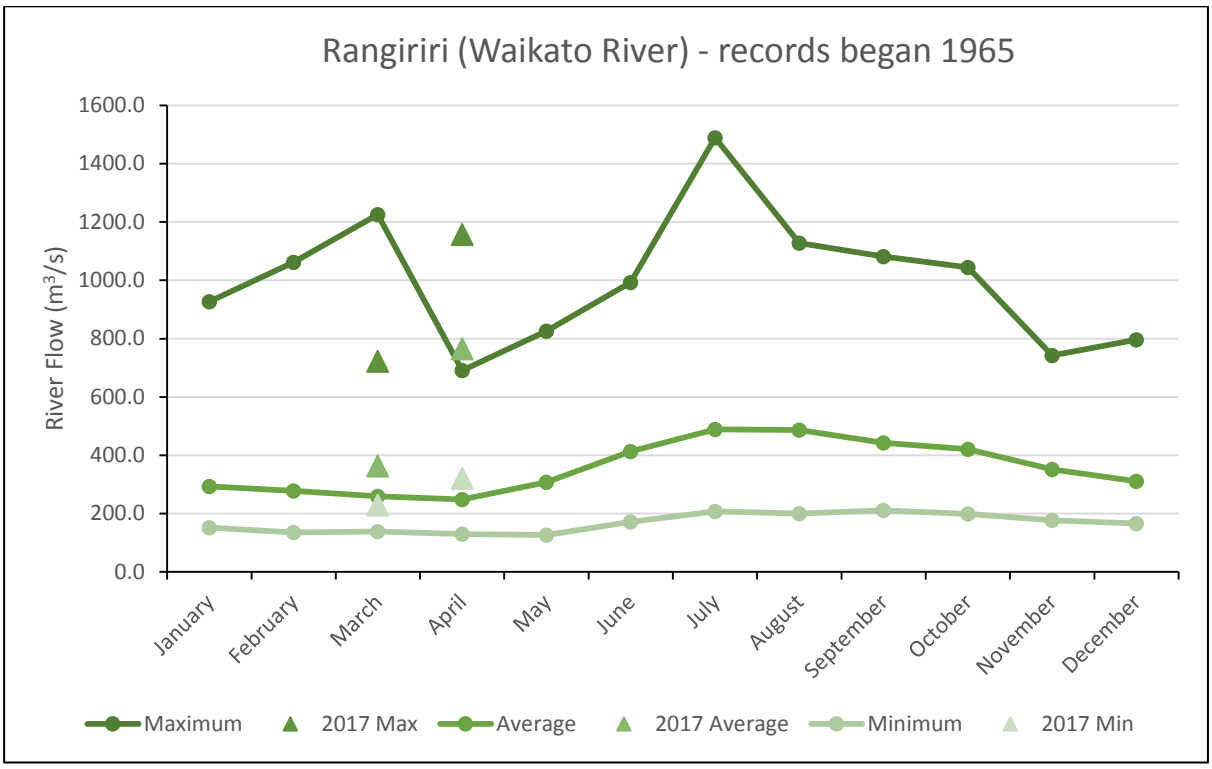


Figure 48: Maximum and minimum river flow values recorded at Rangiriri (Waikato River) during each month over historic records, with monthly averages. March/April 2017 maximums, average, and minimum river flows for comparison.

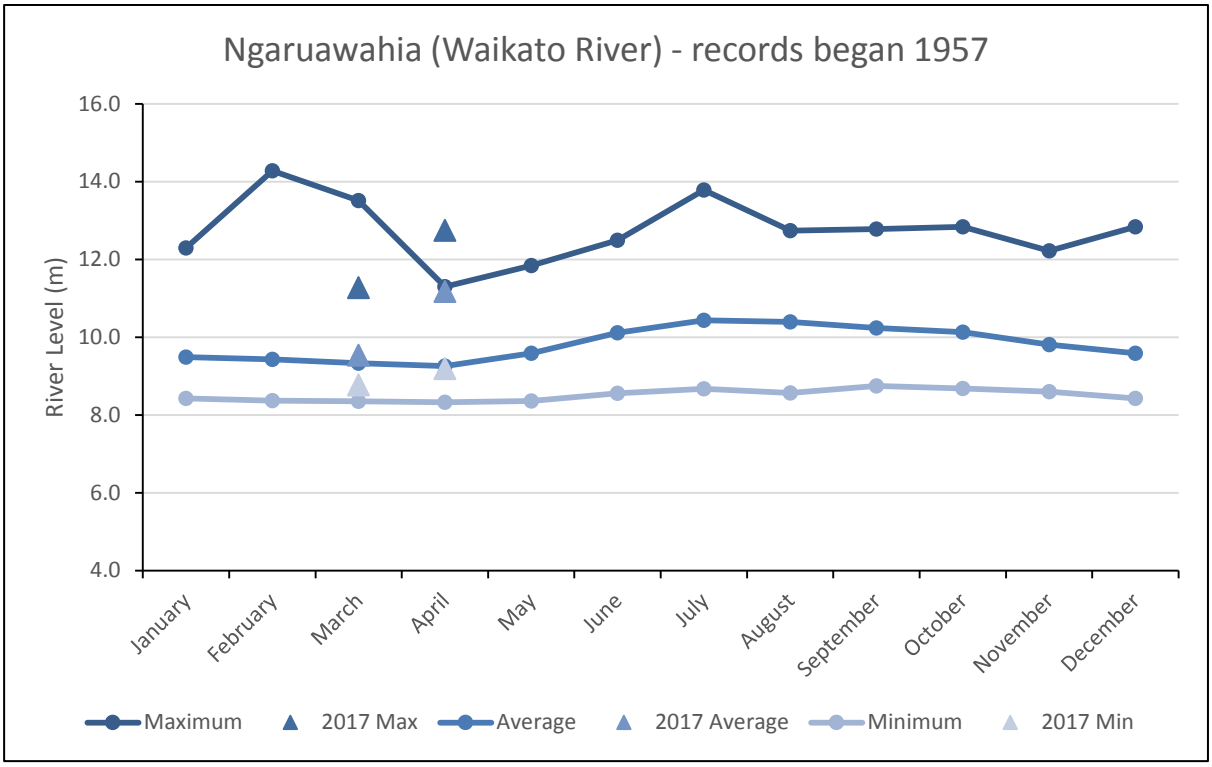


Figure 49: Maximum and minimum river level values recorded at Ngaruawahia (Waikato River) during each month over historic records, with monthly averages. March/April 2017 maximums, average, and minimum river levels for comparison.

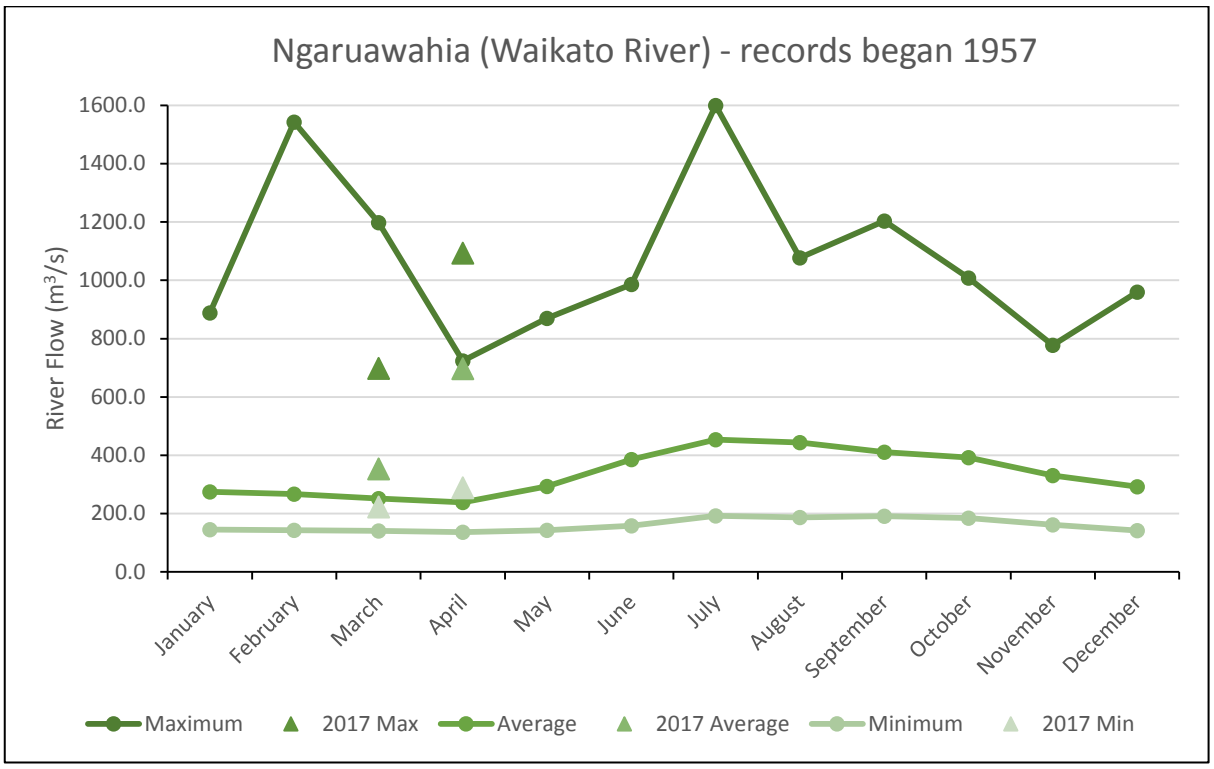


Figure 50: Maximum and minimum river flow values recorded at Ngaruawahia (Waikato River) during each month over historic records, with monthly averages. March/April 2017 maximums, average, and minimum river flows for comparison.

A6.3 Central Waikato/Waipa Zones

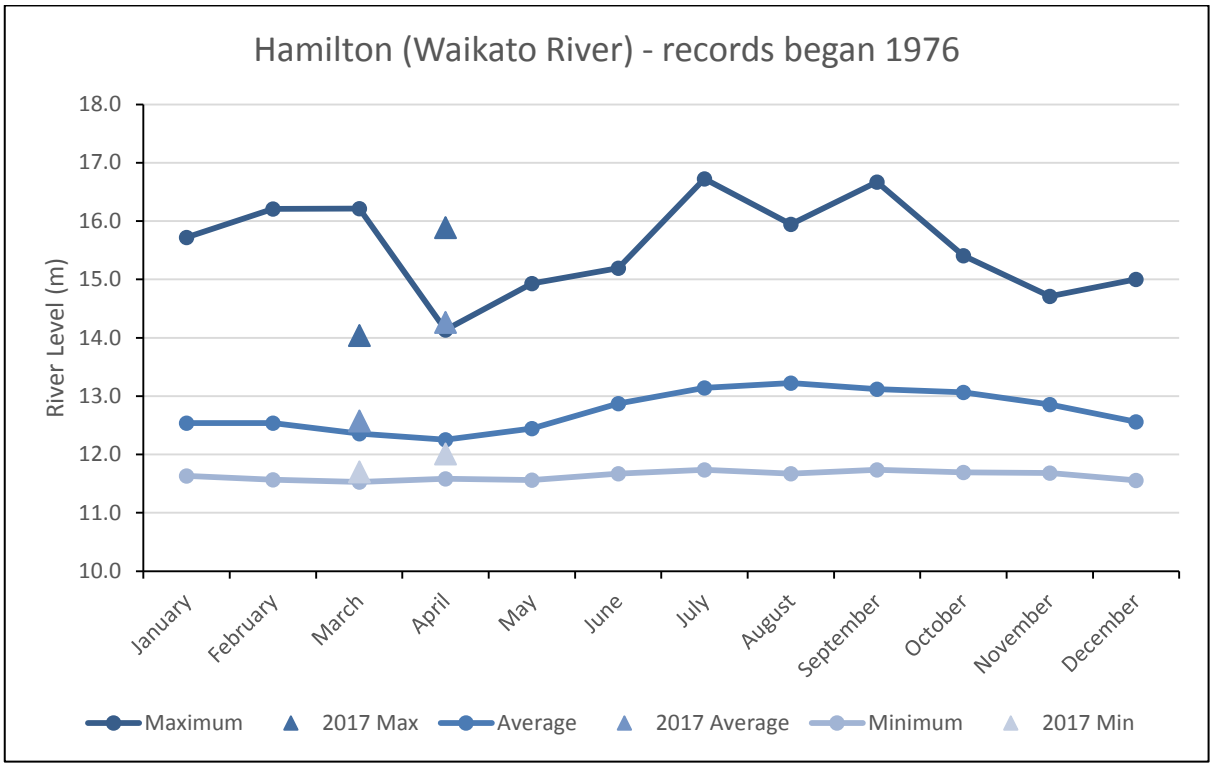


Figure 51: Maximum and minimum river level values recorded at Hamilton (Waikato River) during each month over historic records, with monthly averages. March/April 2017 maximums, average, and minimum river levels for comparison.

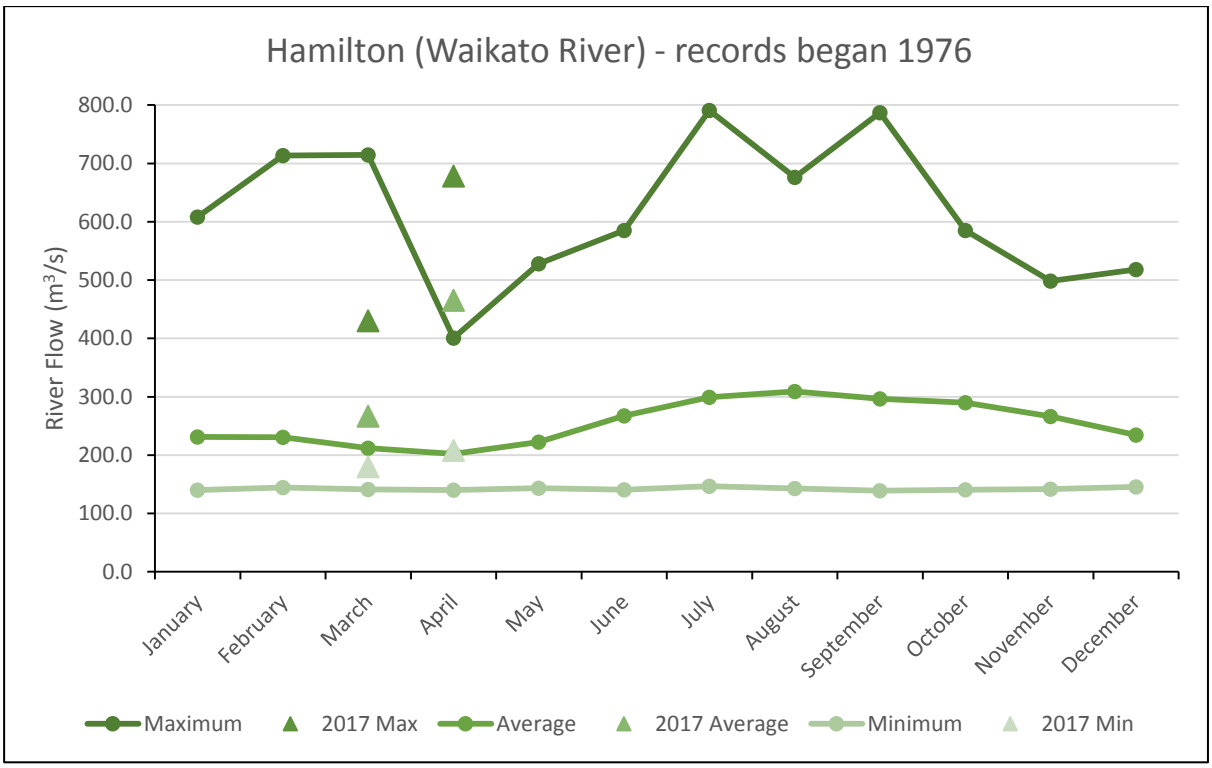


Figure 52: Maximum and minimum river flow values recorded at Hamilton (Waikato River) during each month over historic records, with monthly averages. March/April 2017 maximums, average, and minimum river flows for comparison.

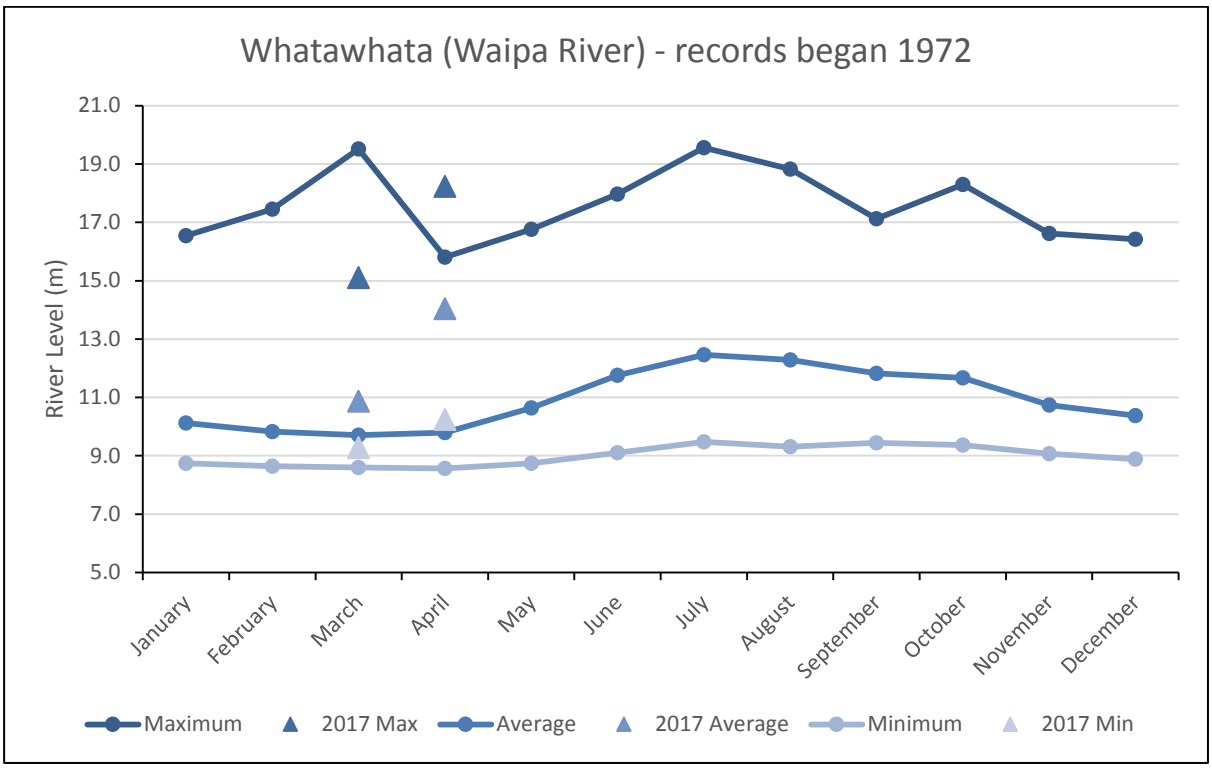


Figure 53: Maximum and minimum river level values recorded at Whatawhata (Waipa River) during each month over historic records, with monthly averages. March/April 2017 maximums, average, and minimum river levels for comparison.

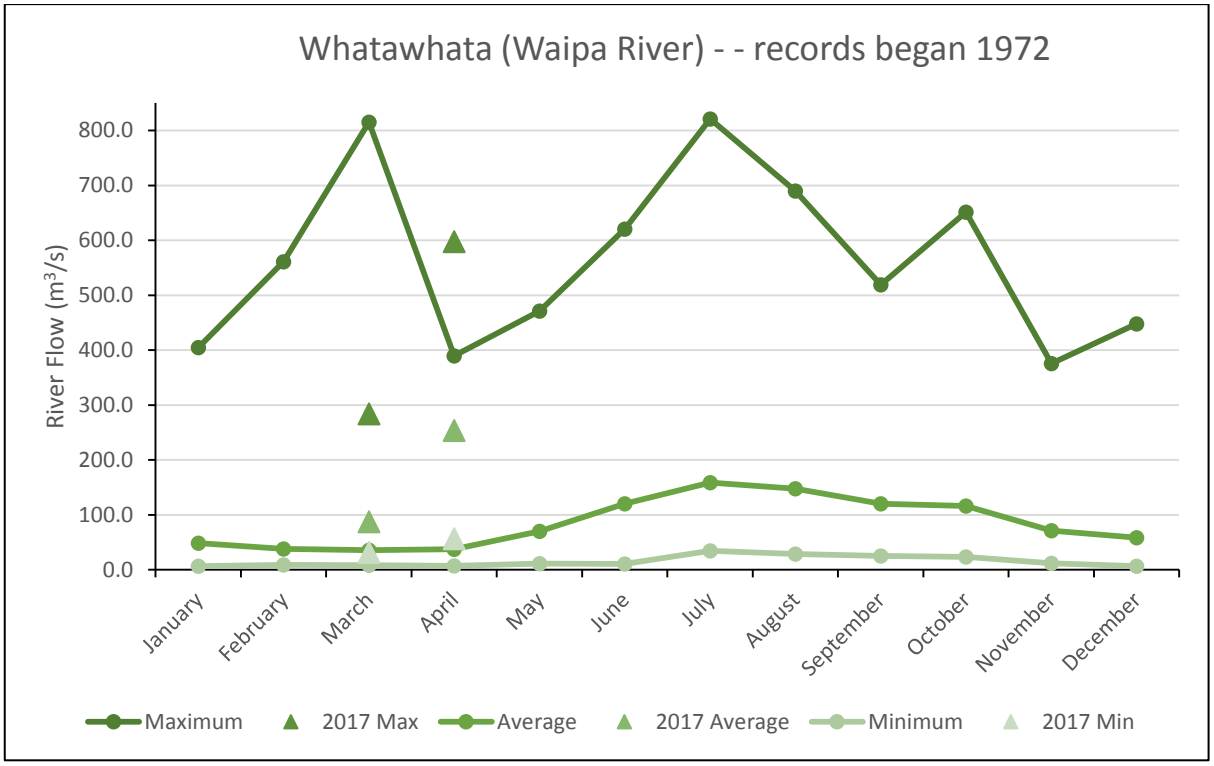


Figure 54: Maximum and minimum river flow values recorded at Whatawhata (Waipa River) during each month over historic records, with monthly averages. March/April 2017 maximums, average, and minimum river flows for comparison.

Appendix 7: Road closures and disruption

Table 45: Major road delays (blue), road hazard (orange), and road closures (red) and disruption in the Coromandel Zone (supplied by NZTA).

Route	Location	Impact	Cause	Start time/date	Length
500m South Of Te Tutu Street	Whangamata	Caution	Slip	04-Apr-2017 20:54:00	1 h, 34 m
2km South Of Blackjack Rd, Kuaotunu	Otapaurau	Delays	Slip	04-Apr-2017 22:07:00	2 d, 10 h, 20 m
Whitianga To Tairua	Whenuakite	Caution	Flooding	05-Apr-2017 00:19:00	3 h, 56 m
Thames To Coromandel	Ruamahunga	Road Closed	Slip	05-Apr-2017 02:17:00	
Thames To Coromandel	Ruamahunga	Road Hazard	Slip	05-Apr-2017 02:59:00	
Thames To Coromandel	Te Puru	Road Closed	Slip	05-Apr-2017 04:23:00	
Thames To Coromandel	Tararu	Road Hazard	Slip	05-Apr-2017 04:58:00	
Between Thames And Coromandel	Kereta	Road Closed	Slip	05-Apr-2017 04:59:00	2 d, 3 h, 10 m
Between Thames And Coromandel	Kereta	Area Warning	Slip	05-Apr-2017 05:02:00	2 d, 3 h, 7 m
Approximately 1km North Of Hikuai Settlement Road, Duck Creek	Duck Creek	Caution	Flooding	05-Apr-2017 06:05:00	3 h, 58 m
Approximately 1km North Of Hikuai Settlement Road, Duck Creek	Hikuai	Road Hazard	Flooding	05-Apr-2017 06:07:00	3 h, 55 m
Near To Sailors Grave Road, Pumpkin Hill	Pumpkin Hill	Caution	Washout	05-Apr-2017 12:31:00	
Whangamata To Waihi	Whiritoa	Caution	Slip	05-Apr-2017 23:22:00	13 h, 41 m
2km South Of Blackjack Rd, Kuaotunu	Kuaotunu	Road Hazard	Slip	06-Apr-2017 08:04:00	4 h, 59 m
Thames To Coromandel	Ruamahunga	Road Closed	Slip	06-Apr-2017 18:48:00	8 d, 16 h, 16 m
2km South Of Te Puru	Thornton Bay	Caution	Slip	07-Apr-2017 04:23:00	1 h, 33 m
Between Thames And Coromandel	Kereta	Road Closed	Slip	07-Apr-2017 08:25:00	4 h, 15 m
Between Thames And Coromandel	Kereta	Area Warning	Slip	07-Apr-2017 08:25:00	4 h, 15 m
Kereta To Ruamahunga	Kereta	Caution	Slip	07-Apr-2017 12:50:00	3 h, 5 m
Thames To Coromandel	Manaia	Caution	Washout	10-Apr-2017 16:26:00	4 d, 18 h, 16 m
Thames To Coromandel	Kereta	Caution	Slip	12-Apr-2017 22:29:00	2 d, 12 h, 12 m
Thames To Coromandel	Te Puru	Road Hazard	Slip	12-Apr-2017 22:43:00	2 d, 12 h, 21 m
Between Tararu To Tapu	Tapu	Road Closed	Slip	13-Apr-2017 05:10:00	2 d, 11 h, 3 m
Between Tararu To Tapu	Tararu	Area Warning	Slip	13-Apr-2017 05:10:00	2 d, 11 h, 3 m
Whitianga To Tairua	Whenuakite	Caution	Flooding	13-Apr-2017 15:38:00	29 m
Hikuai Settlement Road	Duck Creek	Caution	Flooding	13-Apr-2017	2 h, 18 m

				20:48:00	
North Of The Moana-anu-anu River Bridge, Whangamata	Whangamata	Road Closed	Slip	14-Apr-2017 22:36:00	17 h, 28 m
North Of The Moana-anu-anu River Bridge, Whangamata	Whangamata	Road Hazard	Slip	15-Apr-2017 06:35:00	9 h, 29 m
Thames To Coromandel	Kereta	Caution	Washout	15-Apr-2017 10:45:00	
Whakatete Bay	Whakatete Bay	Caution	Slip	15-Apr-2017 16:18:00	
Ruamahunga	Ruamahunga	Caution	Slip	15-Apr-2017 16:20:00	12 d, 22 h, 30 m
Whangamata To Waihi	Whiritoa	Caution	Slip	17-Apr-2017 11:36:00	11 d, 10 m

Table 46: Major road delays (blue), road hazard (orange), and road closures (red) and disruption in the Waihou/Piako Zone (supplied by NZTA).

Route	Location	Impact	Cause	Start time/date	Length
Intersection Oak Street, Morrinsville	Morrinsville	Caution	Flooding	04-Apr-2017 08:16:00	1 h, 31 m
Pokeno To Paeroa	Waitakaruru	Caution	Flooding	05-Apr-2017 03:12:00	1 h, 53 m
Thames To Sh25 Junction	Kopu	Caution	Slip	05-Apr-2017 03:16:00	1 d, 9 h, 19 m
Sh2 Junction To Matamata	Patetonga	Delays	Slip	05-Apr-2017 03:21:00	14 h, 27 m
Kopu To Hikuai	Kopu	Caution	Slip	05-Apr-2017 06:00:00	12 h, 0 m
Pokeno To Paeroa	Waitakaruru	Caution	Flooding	05-Apr-2017 07:04:00	1 h, 0 m
Kuratua Junction	Ngatea	Caution	Slip	05-Apr-2017 07:53:00	31 m
Tauranga To Te Poi	Te Poi	Caution	Slip	05-Apr-2017 14:14:00	1 h, 37 m
Kaihere Summit	Kaihere	Delays	Slip	05-Apr-2017 21:26:00	1 d, 17 h, 57 m
Waitakaruru To Waihi	Waitakaruru	Caution	Slip	07-Apr-2017 08:00:00	48 m
Hamilton To Morrinsville	Motumaoho	Caution	Flooding	12-Apr-2017 16:16:00	5 m
Southern End Of Tirau	Tirau	Caution	Flooding	12-Apr-2017 16:30:00	53 m
Hamilton To Morrinsville	Motumaoho	Caution	Flooding	12-Apr-2017 16:38:00	1 h, 0 m
Paeroa To Waihi	Karangahake	Road Closed	Flooding	12-Apr-2017 16:40:00	1 h, 27 m
Te Aroha To Paeroa	Te Aroha	Caution	Flooding	12-Apr-2017 16:57:00	40 m
Paeroa To Thames	Komata	Caution	Flooding	12-Apr-2017 17:53:00	29 m
Sh2 Junction To Matamata	Tatuanui	Caution	Flooding	12-Apr-2017 18:07:00	57 m
Sh2 Junction To Matamata	Kaihere	Caution	Slip	12-Apr-2017 19:21:00	12 h, 28 m
Paeroa To Waihi	Waikino	Caution	Flooding	12-Apr-2017 20:55:00	9 h, 47 m
Paeroa To Thames	Paeroa	Caution	Slip	12-Apr-2017 23:05:00	36 m

Waihi To Tauranga	Waihi	Caution	Flooding	13-Apr-2017 16:31:00	3 h, 48 m
Near Tui Pa Rd	Te Aroha	Caution	Flooding	13-Apr-2017 16:40:00	3 h, 6 m
Kopu To Paeroa	Kopu	Caution	Flooding	13-Apr-2017 17:04:00	4 h, 13 m
Tirau To Ngongotaha	Ngatira	Caution	Flooding	13-Apr-2017 17:39:00	21 h, 59 m
Te Poi To Sh27 Junction	Te Poi	Caution	Flooding	13-Apr-2017 17:45:00	3 h, 34 m
Sh2 Junction To Matamata	Ngarua	Caution	Flooding	13-Apr-2017 18:17:00	1 h, 27 m
1km South Of Sh25, Mangatarata	Mangatarata	Caution	Slip	13-Apr-2017 18:54:00	6 h, 13 m
Tauranga To Te Poi	Lower Kaimai	Caution	Slip	13-Apr-2017 18:58:00	13 h, 21 m
Paeroa To Waihi	Karangahake	Vehicle Restrictions	Slip	13-Apr-2017 21:33:00	14 d, 14 h, 14 m
Paeroa To Waihi	Karangahake	Road Hazard	Slip	13-Apr-2017 23:53:00	2 h, 34 m
Cambridge To Tokoroa	Tirau	Caution	Slip	14-Apr-2017 01:35:00	1 d, 17 h, 51 m
Te Aroha To Paeroa	Te Aroha	Caution	Flooding	14-Apr-2017 10:03:00	10 h, 42 m
Te Aroha To Paeroa	Te Aroha	Road Hazard	Flooding	14-Apr-2017 14:40:00	6 h, 5 m
At The Intersection Of Paeroa-tahuna Rd	Springdale	Caution	Flooding	14-Apr-2017 17:30:00	3 h, 16 m
875 Sh27 Between Kaihere Rd And Torehape Rd East	Kaihere	Caution	Slip	14-Apr-2017 17:43:00	15 h, 17 m
Thames To Sh25 Junction	Hikuai	Caution	Slip	14-Apr-2017 18:37:00	23 h, 46 m
Rawhiti Road North And Rawhiti Road South, Te Aroha	Te Aroha	Road Closed	Flooding	15-Apr-2017 17:28:00	16 h, 43 m
Rawhiti Road North And Rawhiti Road South, Te Aroha	Te Aroha	Area Warning	Flooding	15-Apr-2017 17:30:00	16 h, 41 m

Table 47: Major road delays (blue), road hazard (orange), and road closures (red) and disruption in the Lower Waikato Zone (supplied by NZTA).

Route	Location	Impact	Cause	Start time/date	Length
Pokeno To Paeroa	Mangatawhiri	Caution	Flooding	04-Apr-2017 21:16:00	10 m
Pioneer Rd, Pokeno	Pokeno	Caution	Flooding	04-Apr-2017 23:21:00	1 d, 9 h, 58 m
Ohinewai	Huntly	Caution	Flooding	05-Apr-2017 04:30:00	1 d, 4 h, 51 m
Armitage Rd, Rangiriri	Rangiriri	Caution	Flooding	05-Apr-2017 04:33:00	5 h, 45 m
Near To The Maramarua Golf Club, Mangatawhiri	Mangatawhiri	Caution	Flooding	05-Apr-2017 06:20:00	1 h, 43 m
Maramarua To Golf Road Underpass	Mangatawhiri	Delays	Flooding	05-Apr-2017 06:23:00	2 h, 33 m
Between Kopuku Road And Coalfields Road - Maramarua	Maramarua	Caution	Flooding	05-Apr-2017 07:16:00	2 h, 44 m
Between Kopuku Road And Coalfields Road - Maramarua	Maramarua	Road Hazard	Flooding	05-Apr-2017 07:20:00	20 m

Sh1 And Sprinhgill Road Meremere	Meremere	Caution	Slip	05-Apr-2017 08:36:00	1 d, 7 h, 16 m
Between Kopuku Road And Coalfields Road - Maramarua	Maramarua	Caution	Flooding	05-Apr-2017 12:56:00	2 h, 35 m
Pokeno To Mangatawhiri	Mangatawhiri	Caution	Slip	05-Apr-2017 20:03:00	12 h, 8 m
Rangiriri Southbound	Rangiriri	Caution	Flooding	06-Apr-2017 00:01:00	4 d, 8 h, 2 m
Ohinewai	Huntly	Caution	Flooding	12-Apr-2017 15:03:00	1 d, 18 h, 44 m
Huntly	Huntly	Caution	Flooding	13-Apr-2017 17:49:00	1 h, 48 m
North Of Huntly Near Ohinewai Road	Ohinewai	Caution	Flooding	13-Apr-2017 18:05:00	20 h, 0 m

Table 48: Major road disruption in the Central Zone (supplied by NZTA).

Route	Location	Impact	Cause	Start time/date	Length
Near Dixon Rd - Glenview	Glenview	Caution	Flooding	04-Apr-2017 07:11:00	18 m
Cobham Dr To Lorne St, Hamilton	Melville	Caution	Flooding	05-Apr-2017 00:23:00	13 m
Cobham Drive	Hamilton East	Caution	Flooding	12-Apr-2017 12:47:00	46 m
Adjacent To Hinurea	Karapiro	Caution	Flooding	14-Apr-2017 16:19:00	1 d, 3 h, 12 m

Table 49: Major road delays (blue), road hazard (orange), and road closures (red) and disruption in the Waipa Zone (supplied by NZTA).

Route	Location	Impact	Cause	Start time/date	Length
Close To Te Pahu Road Northbound	Whatawhata	Caution	Slip	04-Apr-2017 21:24:00	59 m
Te Kuiti To Whakamaru Near The Railway Bridge	Te Kuiti	Caution	Slip	05-Apr-2017 05:52:00	50 m
Near Kakamutu Rd	Otorohanga	Caution	Slip	05-Apr-2017 06:00:00	43 m
Between Glen Tui Lane And Heddon Rd - Whatawhata	Whatawhata	Caution	Flooding	05-Apr-2017 07:05:00	1 d, 2 h, 17 m
Otorohanga To Te Kuiti	Otorohanga	Caution	Slip	05-Apr-2017 12:37:00	19 h, 58 m
Otorohanga To Te Kuiti	Hangatiki	Caution	Slip	05-Apr-2017 12:42:00	6 d, 19 h, 56 m
Hamilton To Te Awamutu	Te Awamutu	Caution	Flooding	12-Apr-2017 14:55:00	42 m
Te Awamutu To Otorohanga	Te Awamutu	Caution	Flooding	12-Apr-2017 14:57:00	39 m

Table 50: Major road delays (blue), road hazard (orange), and road closures (red) and disruption in the Taupō and Upper Waikato Zone (supplied by NZTA).

Route	Location	Impact	Cause	Start time/date	Length
Taupō Zone					
50m South Of Pohokura Road	Waipunga	Caution	Flooding	04-Apr-2017 13:34:00	1 h, 41 m
Waihaha Further Details To Follow	Waihaha	Caution	Slip	05-Apr-2017 07:11:00	7 h, 34 m
Sh32 Junction To Turangi	Kuratau	Caution	Slip	05-Apr-2017 08:25:00	6 h, 2 m
Tokoroa To Turangi	Waihaha	Caution	Slip	05-Apr-2017 08:29:00	5 h, 59 m
Tokoroa To Turangi	Waihaha	Caution	Slip	05-Apr-2017 09:39:00	4 h, 48 m
South Of Old Taupō Road	Kinleith	Caution	Flooding	05-Apr-2017 10:47:00	19 h, 36 m
Taupō To Turangi	Motutere	Caution	Slip	05-Apr-2017 11:28:00	24 m
Near To The Intersection Of Waitapu Rd, Motutere	Bulli Point	Caution	Slip	05-Apr-2017 11:35:00	4 h, 25 m
Near To The Intersection Of Waitapu Rd, Motutere	Motutere	Caution	Slip	05-Apr-2017 11:51:00	4 h, 7 m
Near To The Intersection Of Waitapu Rd, Motutere	Motutere	Road Hazard	Slip	05-Apr-2017 12:11:00	2 h, 43 m
Tokoroa To Turangi	Kuratau	Delays	Slip	05-Apr-2017 14:34:00	49 m
Tokoroa To Turangi	Waihaha	Caution	Slip	05-Apr-2017 16:53:00	45 m
And Coach Road Northbound	Kinleith	Caution	Slip	05-Apr-2017 19:48:00	51 m
Taupō To Turangi	Hatepe	Caution	Slip	05-Apr-2017 22:34:00	6 d, 13 h, 17 m
Waitapu Road	Motutere	Caution	Slip	05-Apr-2017 23:05:00	18 h, 3 m
Taupō To Turangi	Bulli Point	Caution	Slip	06-Apr-2017 05:58:00	5 h, 24 m
Taupō To Turangi	Turangi	Caution	Flooding	06-Apr-2017 07:31:00	3 h, 51 m
Taupō To Napier	Maunganamu	Caution	Slip	06-Apr-2017 18:46:00	5 d, 17 h, 4 m
Taupō To Turangi	Atiamuri	Caution	Slip	07-Apr-2017 15:01:00	1 h, 2 m
Taupō To Turangi	Motutere	Delays	Slip	12-Apr-2017 03:07:00	43 m
Sh32 Junction To Turangi	Kuratau	Caution	Flooding	12-Apr-2017 18:31:00	3 h, 37 m
Whakamaru To Rotorua	Kinleith	Caution	Flooding	12-Apr-2017 23:18:00	1 h, 47 m
Tokoroa To Turangi	Kinleith	Caution	Slip	13-Apr-2017 12:28:00	2 h, 35 m
Near Bulli Point - Motutere	Motutere	Caution	Slip	13-Apr-2017 17:04:00	1 h, 16 m
Taupō To Turangi	Bulli Point	Caution	Slip	13-Apr-2017 17:37:00	44 m

Tokoroa To Turangi	Waihaha	Caution	Slip	13-Apr-2017 17:49:00	10 h, 39 m
Napier To Taupō	Bay View	Caution	Flooding	13-Apr-2017 18:36:00	21 h, 43 m
Kuratau To Tihoi	Kuratau	Caution	Slip	13-Apr-2017 19:28:00	9 h, 2 m
Kuratau To Tihoi	Kuratau	Area Warning	Slip	13-Apr-2017 19:31:00	1 h, 23 m
Whakamaru To Atiamuri	Kinleith	Road Closed	Slip	14-Apr-2017 10:22:00	5 h, 34 m
Whakamaru To Atiamuri	Atiamuri	Road Hazard	Slip	14-Apr-2017 12:08:00	3 h, 48 m
Tokoroa To Turangi	Kinleith	Caution	Slip	15-Apr-2017 07:54:00	5 d, 2 h, 22 m
Sh32 Junction To Turangi	Kuratau	Caution	Washout	15-Apr-2017 18:31:00	2 m
Tokoroa To Turangi	Kuratau	Caution	Slip	17-Apr-2017 10:53:00	3 m
Taumarunui To Sh32 Junction	Kuratau	Caution	Slip	17-Apr-2017 12:28:00	1 h, 56 m
Tokoroa To Turangi	Waihaha	Caution	Slip	17-Apr-2017 12:54:00	2 d, 23 h, 27 m
Upper Waikato Zone					
Mangakino Stream Bridge	Whakamaru	Caution	Flooding	04-Apr-2017 08:42:00	2 h, 24 m
Waiotapu Sh38 Junction To Wairakei Sh1 Junction	Tahorakuri Forest	Caution	Flooding	05-Apr-2017 09:28:00	52 m
Cambridge To Tokoroa	Tokoroa	Caution	Flooding	12-Apr-2017 16:33:00	1 h, 2 m
Whakamaru Road, Mangakino	Mangakino	Caution	Flooding	12-Apr-2017 16:48:00	1 h, 49 m
Cambridge To Tokoroa	Tokoroa	Caution	Flooding	12-Apr-2017 23:10:00	1 h, 30 m
Cambridge To Tokoroa	Piarere	Caution	Slip	13-Apr-2017 19:34:00	6 d, 22 h, 35 m
Cambridge To Tokoroa	Putaruru	Caution	Flooding	14-Apr-2017 11:16:00	4 h, 24 m
Between Tuahu And Holly Roads Ohakuri	Ohakuri	Caution	Slip	14-Apr-2017 19:41:00	52 m

Table 51: Major road delays (blue), road hazard (orange), and road closures (red) and disruption in the West Coast Zone (supplied by NZTA).

Route	Location	Impact	Cause	Start time/date	Length
3km South Of The Awakino Tunnel	Awakino	Caution	Slip	04-Apr-2017 09:01:00	4 h, 31 m
Approximately 15km South Of Piopio	Mahoenui	Caution	Slip	04-Apr-2017 13:14:00	1 h, 1 m
Awakino Tunnel To Tongaporutu	Mokau	Caution	Slip	04-Apr-2017 16:46:00	1 d, 15 h, 47 m
Awakino Tunnel To Tongaporutu	Awakino	Caution	Slip	04-Apr-2017 20:08:00	11 h, 31 m
Awakino Tunnel To Tongaporutu	Awakino	Caution	Flooding	04-Apr-2017 21:33:00	17 h, 48 m
Awakino Tunnel To Tongaporutu	Awakino	Road Hazard	Flooding	04-Apr-2017 21:56:00	17 h, 23 m
Te Kuiti To Whakamaru	Benneydale	Caution	Slip	05-Apr-2017 03:14:00	15 h, 38 m
Te Kuiti To Whakamaru	Benneydale	Caution	Flooding	05-Apr-2017 09:04:00	23 h, 46 m
From Intersection With Sh4 To Mokau	Mokau	Caution	Slip	05-Apr-2017 15:23:00	2 d, 16 h, 3 m
Sh39 Junction To Kawhia	Hauturu	Caution	Flooding	13-Apr-2017 12:43:00	1 h, 14 m
Eight Mile Junction To Taumarunui	Kopaki	Caution	Slip	13-Apr-2017 20:22:00	1 h, 9 m
Near Awakau Road	Awakino	Caution	Slip	15-Apr-2017 17:32:00	1 h, 25 m
Eight Mile Junction To Awakino Tunnel	Piopio	Caution	Slip	17-Apr-2017 06:36:00	2 h, 50 m