IN THE MATTER:	of the Resource Management Act 1991 (**RMA**)
AND	
IN THE MATTER:	Proposed Plan Change 2: Pukehangi Heights to the Rotorua District Plan under Part 5, Sub-Part 5 – Streamlined Planning Process and Schedule 1 Part 5 of the RMA

STATEMENT OF EVIDENCE OF PETER BLACKWOOD ON BEHALF OF BAY OF PLENTY REGIONAL COUNCIL – UTUHINA FLOOD FREQUENCY & RAINFALL TEMPORAL VARIATION

18 September 2020

Qualifications and Experience

1. My full name is Peter Lindsay Blackwood. I hold the position of Principal Technical Engineer at Bay of Plenty Regional Council (**Regional Council**). I have held this position for 3 years.

2. Between 2006 and 2016 I was employed as Manager Design, Manawatu-Whanganui Regional Council, ostensibly to manage the design of a multimillion dollar flood protection works upgrade on the Manawatu, Oroua, Rangitikei and Pohangina Rivers and Mākino Stream and Floodway following the very large 2004 so-called "Manawatu Floods". I also designed the upgrade of stopbanks in Whanganui, including the major Balgownie Industrial Area stopbank

3. I was previously employed by the Regional Council (then known as Environment Bay of Plenty) as Technical Services Manager between 1996 and 2006.

4. In 1988-89 I carried out the full hydrological and hydraulic design of the Lake Rotorua Level Control structure at the entrance to Ōhau Channel. The hydraulic design was complex due to the influence of ambient levels in both Lake Rotorua and Lake Rotoiti on the flows through the structure. The design requirements included detailed hydraulic modelling and rainfall frequency analyses of the Whakarewarewa rain gauge and Ōhau Channel Flows. From this I have a good familiarity of the ambient hydrologic characteristics of the Rotorua Township area.

5. My qualifications include a Bachelor of Engineering (Civil) with Honours degree from Canterbury University.

6. I was awarded the IPENZ Arch Campbell Award for river and catchment engineering in 2015. This award is a national award based on excellence in these disciplines.

7. I have 44 years' experience in central and regional government environmental and civil engineering. My areas of specialist advice include

   (a) Flood and rainfall frequency including detailed assessment of the extreme value frequency distributions and impacts of climatic trends such as the Interdecadal Pacific Oscillation (IPO). This includes research into and co-authoring of specialist computer programmes FRAN and FRANCES for the ex-Ministry of Works. These assessed up to seven different frequency distributions applied to continuous series and censored data.

(b) Climate change policy and design;

(c) River and stream hydraulics;

(d) Design of river protection works;

(e) River and catchment engineering; and

(f) Coastal engineering including impacts of storm surge on coastal inundation

8. My professional memberships include: NZ Hydrological Society and NZ Coastal Society. I was Chair of the organising committee for the 2019 NZ Hydrological Society Conference held in Rotorua.

9. I have read the Expert Witness Code of Conduct set out in the Environment Court's Practice Note 2014 and I agree to comply with it. I confirm that the issues addressed in this statement of evidence are within my area of expertise, except where I state I am relying on the specified evidence of another person. I have not omitted to consider material facts known to me that might alter or detract from my expressed opinion.

Background and Scope of Evidence

10. My evidence relates to the flood risk aspects of the Proposed Plan Change 2. In particular my evidence will cover:

a. The flood frequency estimates for the Utuhina Stream. How these have varied over time and the current design estimates;

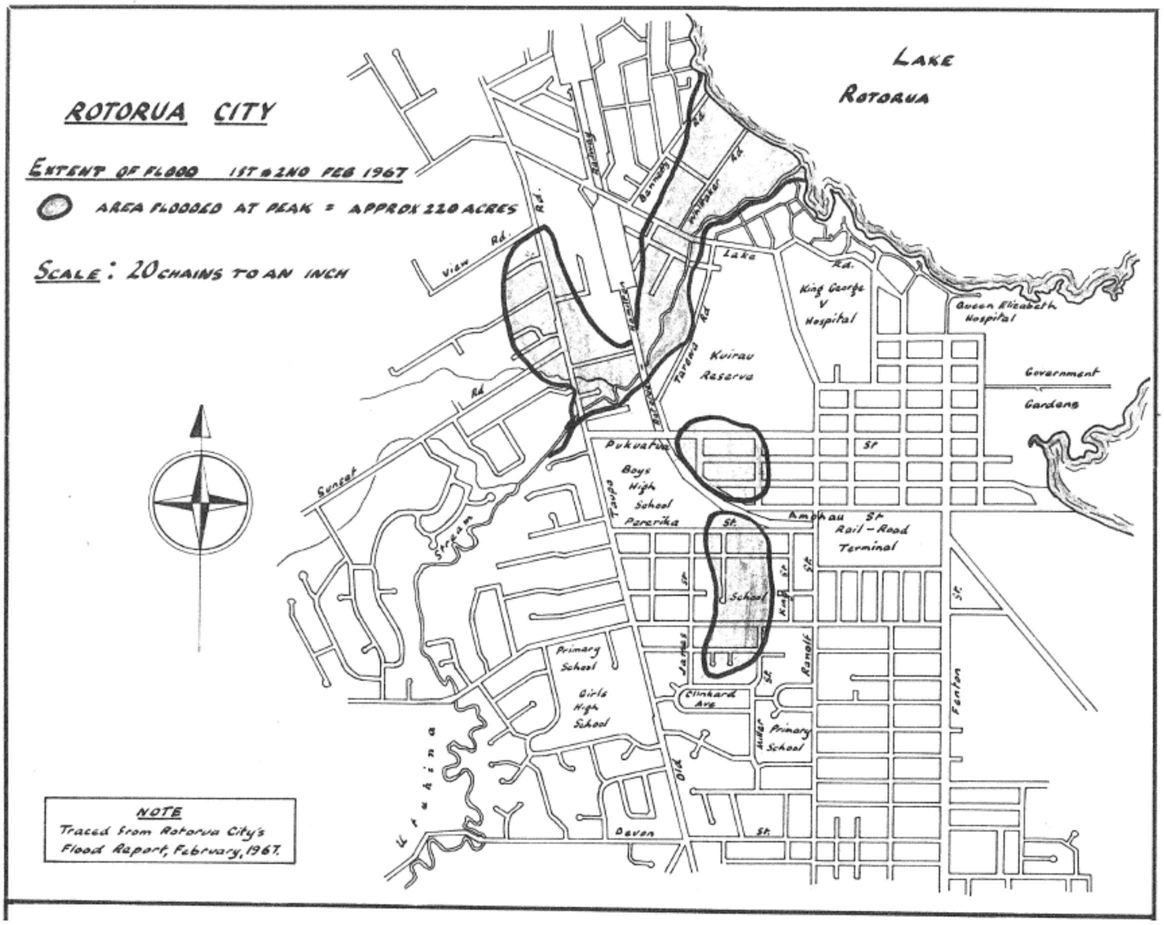
b. A very brief commentary on the relationship between rainfall frequency and flood frequency; and

c. Evidence confirming the centrally located nested hyetograph adopted for modelling is an appropriate design rainfall profile; using the observation of the occurrence in several major storms of the "heavy ended" rainfall profile.

Flood Frequency Estimates for Utuhina Stream

11. Utuhina Stream has a catchment area of 59.6 square kilometres above the recorder located at the State Highway 5 Bridge (at Lake Road). Prior to construction of the Utuhina River stopbanks several areas adjacent to the stream were vulnerable to flooding. Around 57 ha was flooded in the years prior to the flood protection scheme.[1] Please refer to the map dated November 1969 below of the area flooded in the February 1967 flood.[2] [Note: The flooded areas to the south east are largely due to these areas being unable to drain to the flooded stream]

Map 1: 1st & 2nd February 1967 Storm – Areas Flooded



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[1] Section 2.4.7 (a) of *Kaituna Asset Management Plan*, Environment BOP Operations Report 2003/09, October 2003, Philip Wallace, Technical Services Department.
[2] *Kaituna River Major Scheme, Volume 5 Plans Lakes Rotorua and Rotoiti* Bay of Plenty Catchment Commission.

12. Annual maxima peak flows are available on the Utuhina River recorder at State Highway 5 (Lake Road) for the period 1968 to 1996. An assessment of the 1967 flood provided an estimated peak flow of 48.5 cumecs, this being the largest on record, with the 1996 flood of 47.7 cumecs the second largest.

13. Annual maxima peak flows have since been recorded at the Utuhina River at Depot gauge for the period from 2006 to the present day (these are the largest flow in the year, from the continuous series of data recorded). This recorder is located around 700m upstream of the Lake Road gauge and has a catchment area of 56.5 square kilometres. There are only minor inflows between the two recorders, the largest being through a low head 830mm culvert from Kuirau Park at Tarewa Road.

14. The published values of the 1% AEP flood discharge have been periodically updated, as the flow database lengthens. The original scheme documents referenced a 1% AEP ("Q_{100}") of 3820 cusecs, being 108 cumecs.[3] In 2003 the Kaituna Asset Management Plan (referenced in paragraph 11) advised a 1% AEP value of 68 cumecs – based on a flood frequency analysis of the Utuhina at Lake Road recorder site. Both these flood frequency discharge estimates during this period were above today's values, due to a period of abnormally high floods.

15. The 1% AEP value decreased to 55 cumecs (and the 2% AEP 47 cumecs) following a flood frequency analysis of the combined sites for the period 1968-1996 and 2006-2012. This value was based on application of the Log Pearson 3 distribution, with the General Extreme Value distribution just 2 cumecs higher at 57 cumecs. The annual maxima for the Depot Gauge was increased by 10% to represent the flow at the SH5 site, following an assessment of the 29 January 2011 flood (which showed an 8% increase). Importantly the data used does not include the large 1 May 1999 flood (which caused the cancellation of the Rotorua Fletcher Marathon, due to the intense rainfall and significant flooding). There was no gauge to record this flood but a detailed assessment concluded a peak discharge of around 32 cumecs.[4] [Inclusion of the flood in the assessment is complex in creating a homogeneous dataset, and would likely only minorly increase design flows.]

16. The report entitled "*Rivers and Drainage Asset Management Plan 2018-2068*", Bay of Plenty Regional Council advises the 1% AEP value of 55 cumecs for the Utuhina Stream.

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[3] (Reference Table 5.4.IV of *Upper Kaituna Major Scheme – Lakes Rotorua and Rotoiti*, Volume 4, undated c 1969, A.P.Griffiths, Bay of Plenty Catchment Commission).

17. Following the resumption of my duties at Bay of Plenty Regional Council I critically reviewed the flood frequency distribution for the Utuhina Stream at SH5, applying the updated data now available through to 2017. Again the estimated figure of 32 cumecs for the 1999 storm were not included. However, I did not apply any increase in the size of the flows recorded at the Depot Street gauge (to infer possible flows at the original SH5 recorder site). The arguments for increasing, or not, the flows are complex and the impact is small. However, the data considered in my analysis could not in any way be considered conservative.

18. The conclusions from application of the Log Pearson 3 distribution to the lengthened database, were that the estimated values were only minorly different to the previous analyses (refer paragraph 16) were very similar to. The estimates are presented below. As the database expands, minor changes will occur in the design flood frequency estimates. This is a minor shift of around 4% and in my opinion not a wise basis to lower the 1% AEP design flow from 55 cumecs.

- 1% AEP of 53 cumecs
- 2% AEP 45 cumecs

19. Figure One, Appendix 1 presents the flood frequency analysis.

20. **Conclusions**

I. Detailed frequency analyses have been periodically carried out as the database of annual maximum flows on the Utuhina Stream lengthens.

II. These analyses in recent years have combined the data from both the original Lake Road and the additional Depot Street recorder sites.

III. The design 1% AEP flow of 55 cumecs is confirmed as a reliable design estimate for the Utuhina Stream at State Highway 5 site.

Relationships Between Rainfall Frequency and Flood Frequency

21. The evidence from Mark Stuart Pennington dwells at length on the relationship and at times a “mis-match” between rainfall frequency and flood frequency. Quite correctly in paragraph 28 of his evidence Mr Pennington refers to the case of the 28 January 2011 flood in which a 6-hour rainfall of a 44-year ARI (Annual recurrence interval) resulted in a peak discharge of 18-year ARI. In paragraphs 29 and 30 several hydrologically plausible reasons are advance for this “mis-match”. In particular the Kaituna at Whakarewarewa raingauge is not within the Utuhina catchment. Radar imagery of the 28-29 April 2018 heavy rainfall event showed a big variation in rainfalls across the catchments at Rotorua City (refer also paragraph 51).

22. However, to present the total picture, the likelihood of whether a rainfall of a particular frequency or ARI results in a flood of smaller or larger ARI are random – depending on several factors of which Mr Pennington has enumerated a few.

23. It is most important to present that the reverse may well occur in which a rainfall of a given ARI may result in a flood of a larger ARI. This typically happens when the catchment is wetter than normal prior to the onset of the rainfall event. In Table 1 appended to the Mr Pennington’s evidence there are 11 of the 15 presented storms where the ARI of the flood peaks are greater than the ARI of the rainfall.

24. As a minor note the return period of the rainfall of 263 years for the storm of 29 April 2018 should be discounted, as the event duration of 3 hours is well below the time of concentration of the catchment of around 6 hours.

25. As advised in a subsequent paragraph (49), in the flooding of the Bay of Plenty over 3-7 April 2017, the flood peaks in the both lower Whakatāne River and Rangitāiki River (as measured by inflows to Matahina Dam) were record values and well over the 1% AEP flood size. However, in the catchments upstream of these sites only one raingauge recorded anywhere near a 1% AEP rainfall – being the 24-72 hour rainfalls for the Rangitāiki at Aniwhenua gauge. Other catchment gauges recorded rainfalls of generally 2% AEP or smaller. The main reason being that for the preceding month of March the six raingauges upstream of the lower rivers averaged a substantial 314

percent of the normal monthly rainfall.[5] The catchments were very wet and flood sizes were larger than normal.

Conclusion

26. The application of, for instance a 1% AEP design rainfall (with the appropriate methodology and areal reduction factors), to estimate a 1% AEP flood flow is an accepted methodology by the hydrological profession. As we are dealing with nature, then the exactitudes of other scientific disciplines are impossible to satisfy. However, this an internationally accepted methodology applied universally.

[5] Reference *Hydro-meteorological Report of April 2017 Storm Event & Cyclone Cook*, 2 June 2017, Glenn Ellery, Environmental Publication 2017/03.

Storm Temporal Rainfall Profile

27. Section 3.1.2.2 of the Rotorua Lakes Council Stormwater Report advises "*the use of 'nested' storms tends to produce much higher peak discharge when compared to either normalised storm hyetographs (based on 'typical' observed storm events) (McConchie, 2019), flood frequency analysis using observed flow data, or other industry standard temporal patterns, like those identified within recent national guidance (NIWA, 2018).*"

28. The temporal pattern (or profile) is a description of how rainfall intensities vary through the design storm.

29. I do not agree with the ramifications of Section 3.1.2.2. Indeed there is good evidence to suggest that there are other hyetograph profiles that produce higher flows that should be considered. However, the BOPRC designers collegially agreed to go with the centrally located "nested" storm as a good middle of the road approach. This is outlined in the following paragraphs.

30. Section 3.1.2.2 of the Rotorua Lakes Council Stormwater Report also advises "*At this stage, to allow for compatibility with the BOPRC model for the effects assessment, this approach has been used to identify the attenuation requirements for the rezoning of land. This is an appropriately conservative approach for this plan change purpose. Given the current subdivision consenting approaches around the Region, where typically temporal patterns from (NIWA, 2018) (or its predecessor versions) up to and including the 24-hour duration nested storm have been deemed suitable to allow for the assessment of effects, we consider this approach conservative for attenuation design purposes. Further design phases may need to be undertaken using a different, frequency-based approach.*"

31. Furthermore in Section 3.1.3 the report states "*A review of the rainfall record and model performance, shows that the rainfall approach is conservative in nature given that the time of concentration for the Utuhina catchment is less than 12 hours and the 'synthetic' nature of an event*."

32. Furthermore in Section 3.1.6 the report states "*The use of a 72-hour storm nested hyetograph for modelling is likely to produce appropriately conservative results for the catchment flooding assessment, suitable for the plan change stage. The local rainfall and flow data show that discrete storms are typically less than 12 hours, with a quick response time and sharp 'peak' in the resulting hydrograph; and agreement should be sought to determine the appropriate design approach moving forwards to respond to the catchment requirements for subsequent design stages*."

33. The statement in Section 3.1.6 concords well with the matters agreed in Section 12.a. of the Joint Witness Statement, that the analyses are "appropriately conservative" and "The stormwater report is to be amended accordingly". The statements in Sections 3.1.2.2 and 3.1.3 do not reflect the matters agreed. Consequently it has been necessary to present the following paragraphs in my evidence.

34. Mr West in his evidence will present recorded raingauge hyetographs demonstrating that the 'nested' storm is certainly observable in the available rainfall records and in particular the pre-wetting rainfall on the rising limb is clear. I will not comment further on this point.

35. I was part of the team of Regional Council reviewers of the recent national guidance (NIWA, 2018). The methodology was extensively discussed and is based on the method of "Averaged Variability" as presented previous versions of the document *Australian Rainfall and Runoff – A Guide for Flood Estimation*[6].

36. The current version of this document 2019 changes the advice to the application of **ensemble storms** particular in Sections 5.5[7] . This is because, on its own the use of the "Averaged Variability" was inadequate to describe appropriate design temporal rainfall profiles – and in particular the "heavy ended" storm profile was likely to be lost from design considerations.

37. Section 5 and in particular Sections 5.5 and 5.92 of this document provide detailed information on the design temporal rainfall profile . The introductory statement in Section 5.1 states: "*The majority of hydrograph estimation methods used for flood estimation require a temporal pattern that describes how rainfall falls over time as a design input. Traditionally a single burst temporal pattern has been used for each rainfall event duration. The use of a single pattern has been questioned for some time (Nathan and Weinmann, 1995) as the analysis of observed rainfall events from even a single pluviograph shows that a wide variety of temporal patterns is possible.*

The importance of temporal patterns has increased as the practice of flood estimation has evolved from peak flow estimation to full hydrograph estimation. There has been a strong move toward storage-based mitigation solutions in urban catchments which require realistic temporal patterns that reproduce total storm volumes as well as the temporal distribution of rainfall within the event."

[6] Government of Australia.
[7] Reference Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors), *Australian Rainfall and Runoff: A Guide to Flood Estimation*, Commonwealth of Australia (Geoscience Australia), 2019

38. Section 5.9.2 of ARR (2019) states: "*The use of an ensemble of 10 temporal patterns as discussed in Book 2, Chapter 5, Section 5 is recommended. The temporal patterns have been chosen to represent the variability in observed patterns"; and "The ensemble of 10 pattern provides a range of plausible answers. The practitioner should consider the benefits of investigating multiple temporal patterns or Monte Carlo for sensitive designs and solutions*."

39. To put the advice into context Section 5.9.2 of ARR (2019) also states "*It is not recommended that the temporal pattern that represents the worst (or best) case be used by itself for design. Testing has demonstrated that on most catchments large number of events in the ensemble patterns are clustered around the mean and median.*"

40. Therefore I have not advocated that the worst case "heavy ended" storm be the basis for temporal profile. However, I would just note that the downstream catchment is indeed "sensitive" to the addition of stormwater flows.

41. The following paragraphs of evidence confirm the adopted centrally located nested hyetograph is an appropriate rainfall profile; with the observation of the occurrence in several major storms of the "heavy ended" rainfall profile. In the "heavy ended" storm the rainfall has a significant peak at the tail end of the storm. Heavy ended storms are expected to generate larger peak flows as the most intense rain falls on a more saturated catchment. However, I must stress that the adopted design 72-hour nested storm is centrally located and not heavy ended. Therefore, it is certainly not conservative.

42. The following identified "heavy ended" storms are in the main very major storms. As such they require detailed examination for the design ramifications.

    a. 1 May 1999 "Fletcher Marathon flood"

    b. 18 May 2005 Matatā and Tauranga thunderstorms

    c. 3-7 April 2017 "Edgecumbe" Flood

    d. 28-29 April 2018 Rotorua Storm

    e. 25-26 December 2019 Rotorua Storm

    f. 20-21 June 2015 Great Whanganui flood

43. I have very good familiarity of the important characteristics of all the above storms, as I was a Flood Manager in all except storm e (25-26 December 2019 Rotorua Storm); and I was consulted during this storm, whilst on leave in Melbourne.

44. **1 May 1999 “Fletcher Marathon Flood”**

This flood is significant for extensive flooding of Rotorua on 1 May 1999, following heavy overnight rain, resulting in the cancellation of the Fletcher Challenge Marathon – a nationally recognised sport event. Pertinent information on this flood includes:

- Following significant overnight rain at the Mangorewa gauge totalling 96.5mm (at the Flood Managers 0930 assessment), with continued heavy rain, a one-hour fall of 74mm occurred between 124500 and 134500 hours.
- This resulted in a 6.9 metres rise in 1 hour and 45 minutes at the Mangorewa River at Saunders river recorder.
- The duration of the rainfall was close to 24 hours and the 24 hour rainfall at Mangorewa was 275.5mm.
- The peak one-hour fall occurred approximately between 19 and 20 hours in the 24 hour period – thus peaking at around 80% of the storm duration.
- Whilst this storm was not understood as a “heavy ended” rainfall at the time, it quite clearly was. The effects of major flood flows from the late high intensity rainfalls were of course evident.

45. **18 May 2005 Matatā and Tauranga thunderstorms**

This event was notable for the extreme flooding of Matatā from the formation of lahars due to heavy rain late in the storm on a saturated catchment, furthermore major geotechnical problems with slipping at Tauranga. The event was an extreme case of severe convection. The actual cause seems to have been a combination of abnormally warm, moist air, very unstable conditions and most importantly of all, a near stationary convergence line along the coastal fringe from Eastern Coromandel to Bay of Plenty. This enabled the torrential downpours and thunderstorms to continue to re-form in the same area over many hours (Reference *Statement of Evidence of Peter Blackwood on Behalf of Whakatāne District Council: Engineering – Meteorology,* 11 August 2010).

46. Unfortunately, there were no automatic or manual rain gauges in the storm centre for the Matatā Township. The closest automatic raingauge was at Awakaponga some 6 km SSE of Matatā. At this gauge 112mm of rain fell in 75 minutes at the Tarawera at Awakaponga raingauge, following rainfall of close to 150mm in the previous 24 hours, with 11.5mm of rainfall in the preceding 6 hours

47. Figures 2 and 3 in Appendix 2 show the hyetographs at the Awakaponga and TCC Ngatai Road raingauges. This is a prime example of a very heavy ended storm.

48. **3-7 April 2017 "Edgecumbe" Flood**

In the flooding of the Bay of Plenty over 3-7 April 2017, the flood peaks in the both the lower Whakatāne River and Rangitāiki River (as measured by inflows to Matahina Dam) were record values and well over the 1% AEP flood size. A major factor in causing these very high flows was an intense belt of rain near the tail of the storm.

49. The heavy ended characteristic is evident in both Rotorua and eastern Bay of Plenty hyetographs. Refer Figure 4 to 6 in Appendix 2. As a consequence and based on the average shape of these temporal profiles, BOPRC are apply a nested storm peaking at the ¾ duration for the current design scenarios for the Rangitāiki-Tarawera River modelling.

50. **28-29 April 2018 Rotorua Storm**

This intense rainfalls from this storm affected several parts of Rotorua City. It resulted in a close to 1% AEP storm in the Ngongotahā Stream and around a 10% AEP flood in the Utuhina Stream. It is again a heavy ended storm. Presented in Figure 7 in Appendix 2 (sourced from WSP Stormwater Report).

51. **25-26 December 2019 storm**

This is again a heavy ended storm. Presented in Figure 8 in Appendix 2 (Sourced from WSP Stormwater Report)

52. **20-21 June 2015 Great Whanganui flood**

This was a very major flood causing extensive flooding to Whanganui City (with houses flooded to depths up to 2.0m in Anzac Parade). The estimated peak flow of 5,300 cumecs through the Whanganui City reach is the second highest recorded flood flow in the North Island – only beaten by the 1938 Mohaka River flood. Significant rain occurred in the lower catchment as the floodwave arrived. The other significant feature was the significant rainfall in the second half of the storm. Refer to Figure 10 in Appendix 2 for the rainfall at Whanganui at Te Rewa (sited in the lower reaches of the catchment). Whilst the one hour rainfall peaked in roughly the middle of the storm, there is then a 5 hour burst of heavy rain, followed by an approximately 2 hour burst at the tail – all this being conducive to very high river flows. Refer Figure 9 in Appendix 2.

53. **Conclusions**

I. Heavy ended storms are expected to generate larger peak flows as the most intense rain falls on a more saturated catchment.

II. As there is strong evidence of their regularity, the assessment of heavy ended storms for developments in sensitive catchments in line with ARR (2019) is proposed to be included in the next update to the document "Hydrological and Hydraulic Guidelines", Bay of Plenty Regional Council Guideline 2012/02.

III. However, I must stress that the adopted design 72-hour nested storm is centrally located and not heavy ended. Therefore, it is certainly not conservative.

Overall Conclusions

54. In summary:

I. The design 1% AEP flow of 55 cumecs is confirmed.

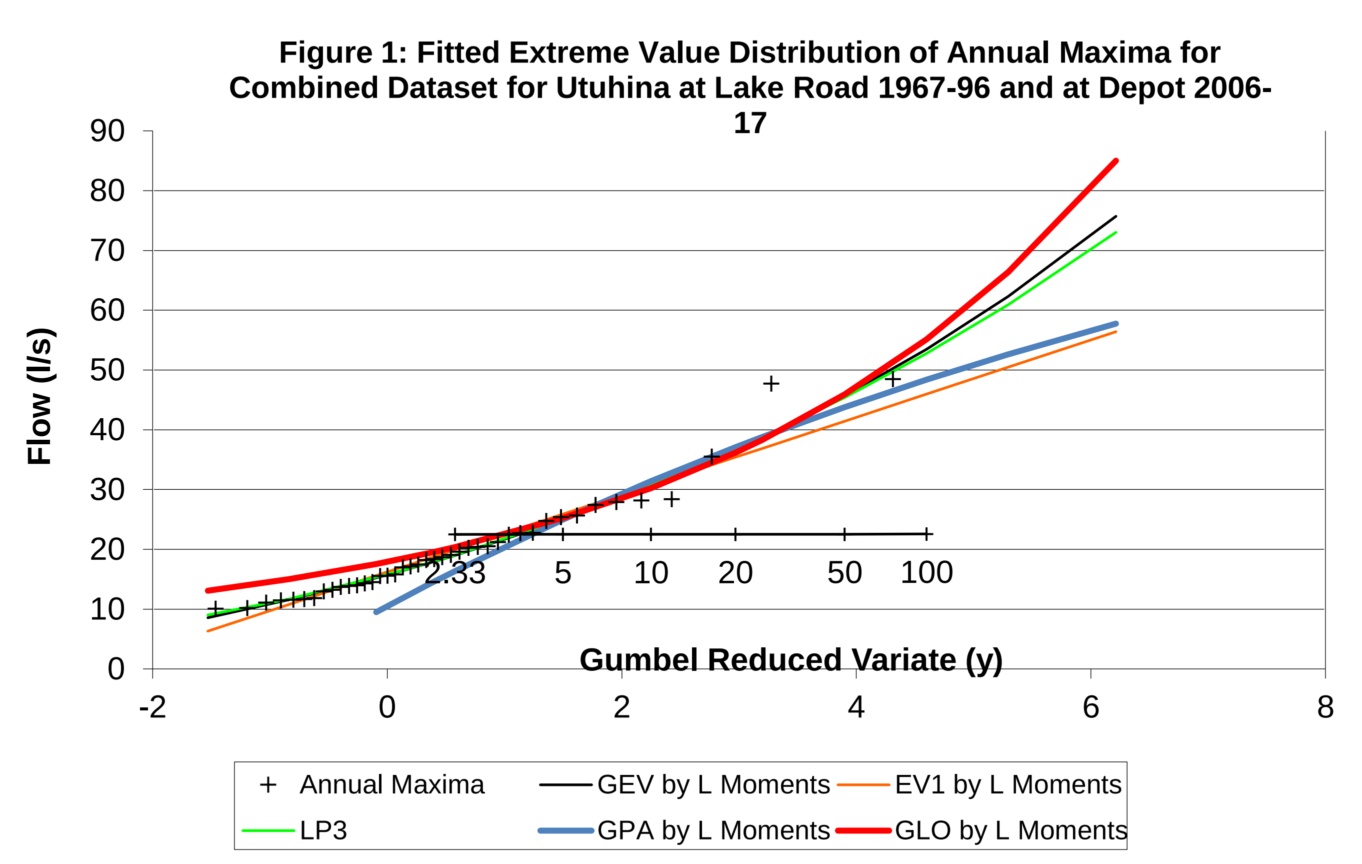
II. There is strong evidence of the regularity of heavy ended storms. With the latest knowledge gained these should normally be assessed in sensitive catchments in line with ARR (2019).

III. The adopted design 72-hour nested storm is centrally located and not heavy ended. Therefore, it is certainly not conservative.

DATE 18 September 2020

Peter Blackwood

APPENDIX 1 – Flood Frequency Analyses for Utuhina Stream



APPENDIX 2 – Recorded Rainfall Hyetographs

Figure 2: Tarawera at Awakaponga Raingauge – Rainfall Event of 18 May 2005 (15 minute rainfalls)

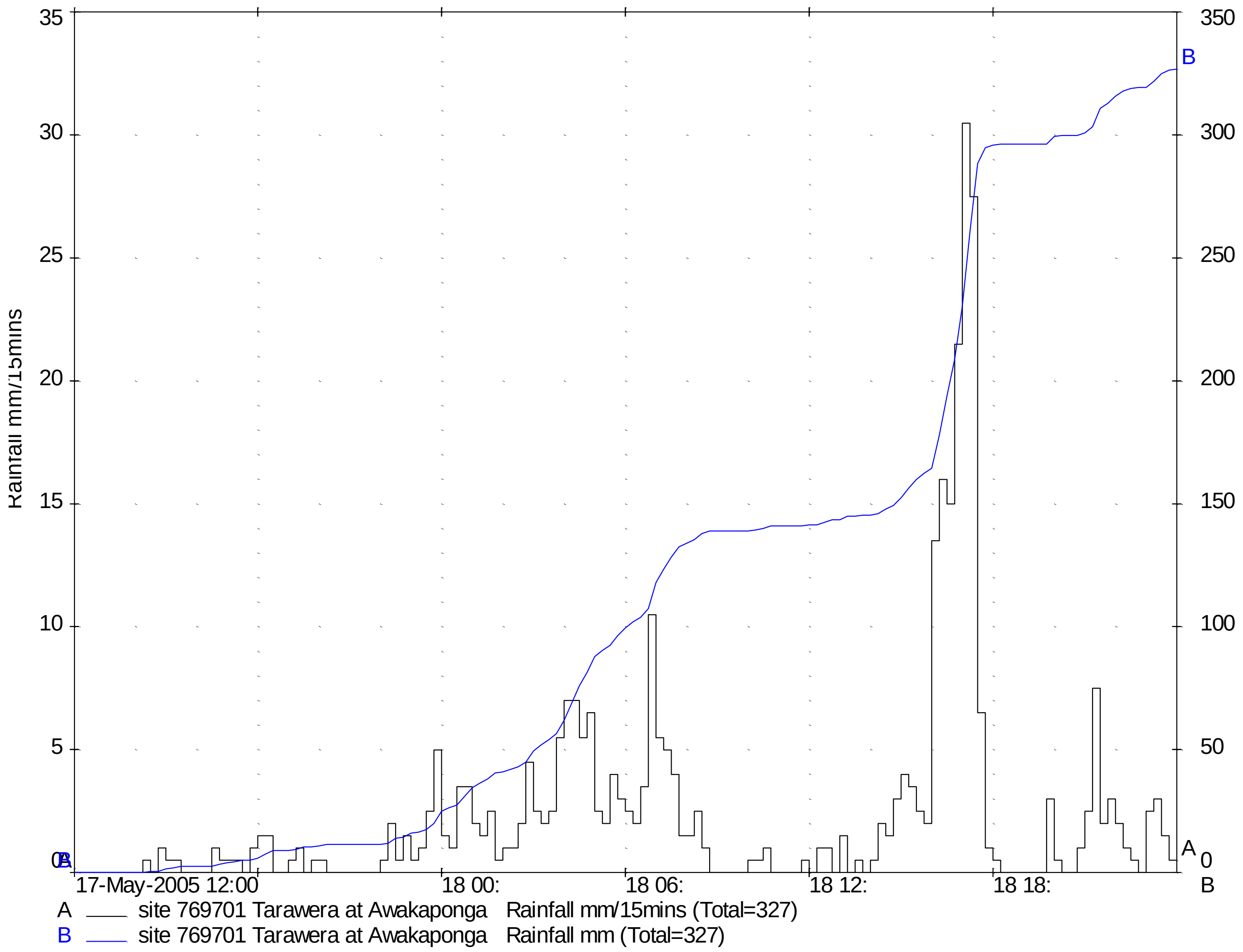


Figure 3: Ngatai Road Raingauge – Rainfall Event of 18 May 2005 (5 minute rainfalls)

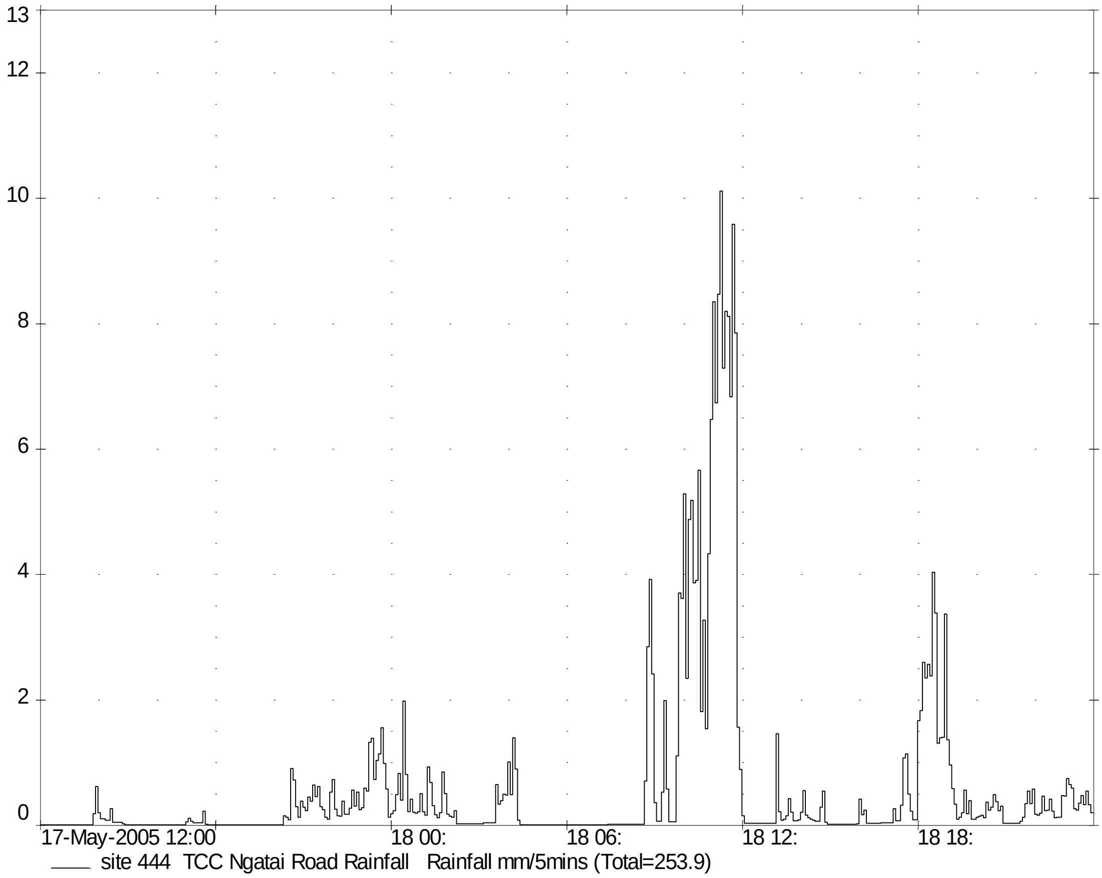


Figure 4: Kaituna at Whakarewarewa – Rainfall Event of 3-7 April 2017

BAY OF PLENTY REGIONAL COUNCIL TOI MOANA

Kaituna at Whakarewarewa

Apr 28, 2017 | 1 of 1

Period Selected: 2017-04-03 00:00:00 - 2017-04-07 00:00:00

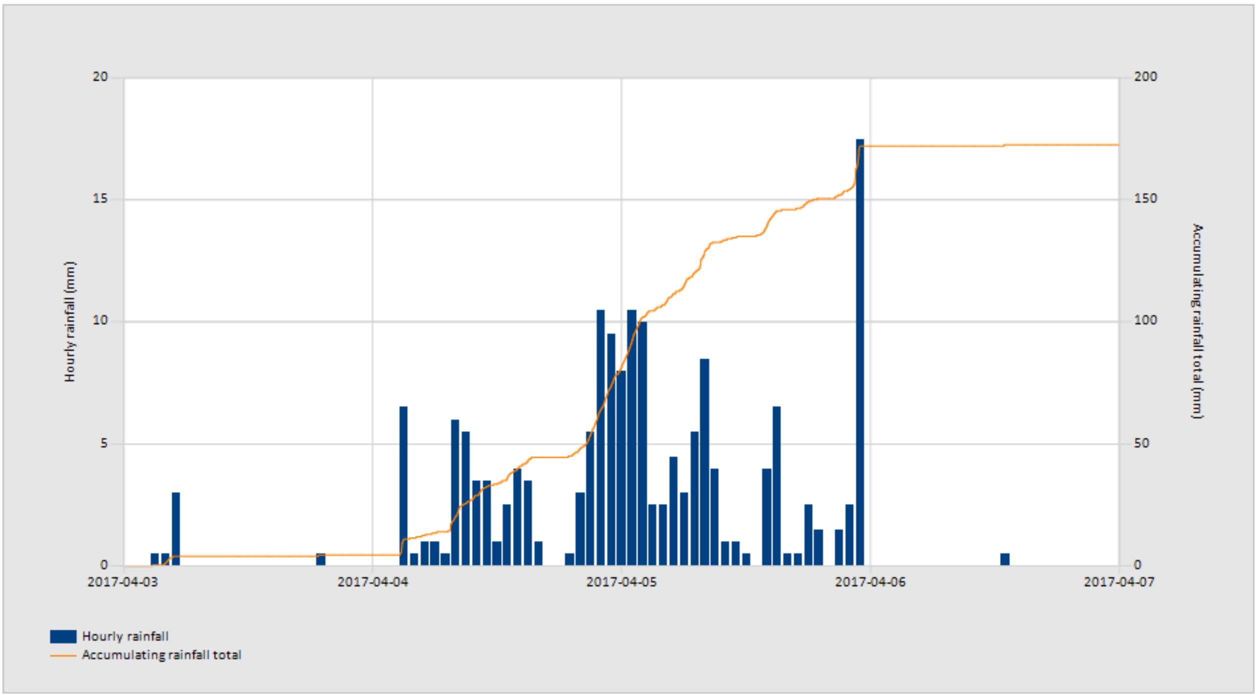


Figure 5: Whakatāne at Huitieke Raingauge – Rainfall Event of 3-7 April 2017

BAY OF PLENTY REGIONAL COUNCIL TOI MOANA

Whakatane at Huitieke Upper

Apr 27, 2017 | 1 of 1

Period Selected: 2017-04-03 00:00:00 - 2017-04-07 00:00:00

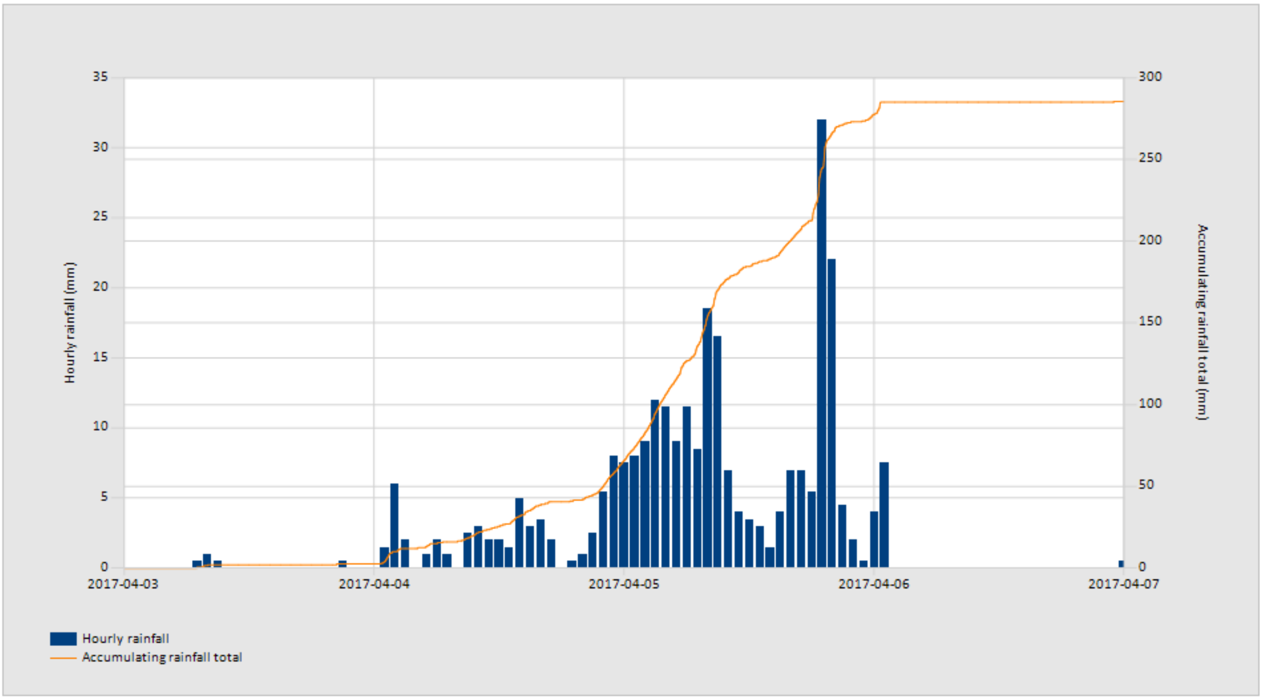


Figure 6: Waihua at Clearing Raingauge – Rainfall Event of 3-7 April 2017

BAY OF PLENTY REGIONAL COUNCIL TOI MOANA

Waihua at Clearing

Apr 27, 2017 | 1 of 1

Period Selected: 2017-04-03 00:00:00 - 2017-04-07 00:00:00

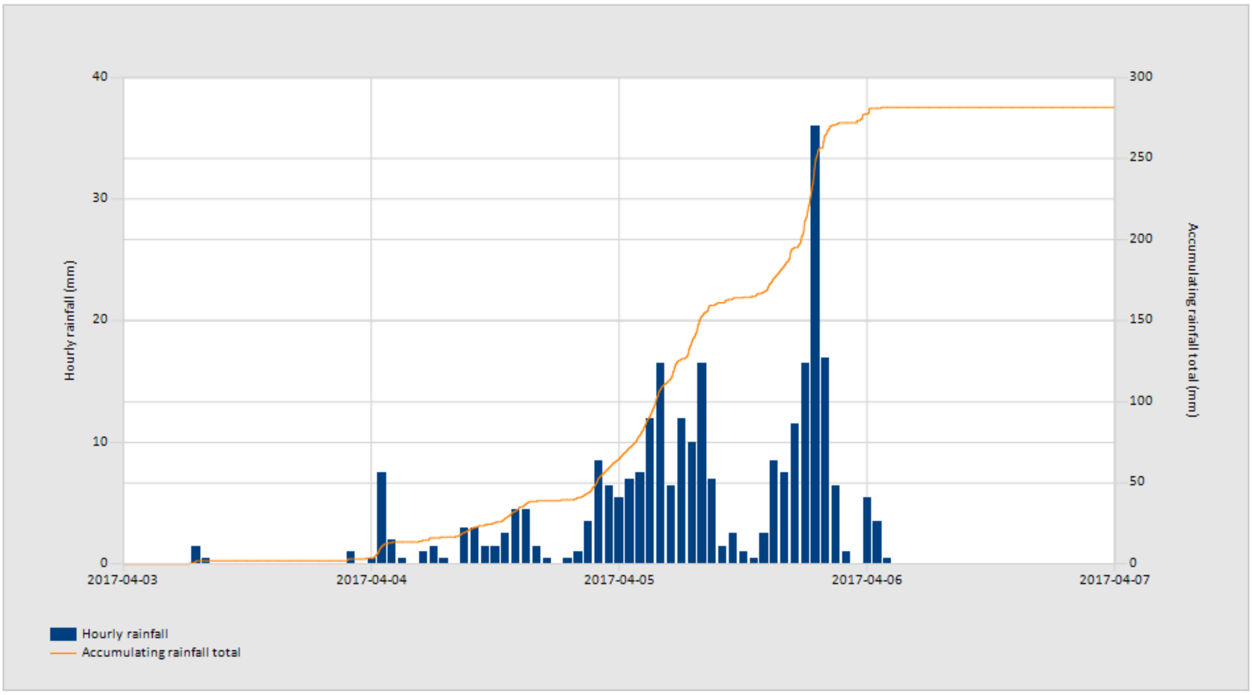


Figure 7: Rotorua Raingauges – Rainfall Event of 28-29 April 2018

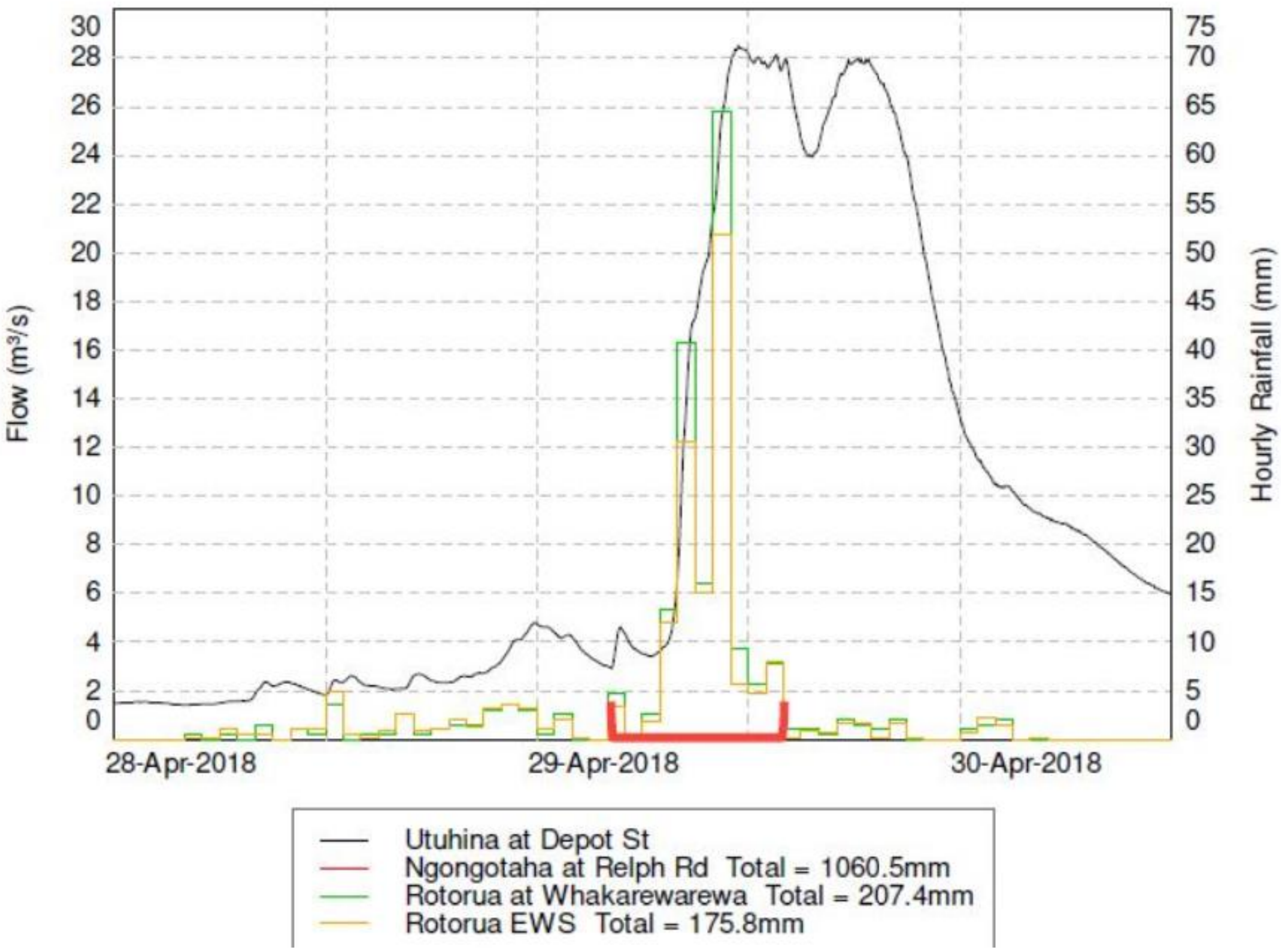
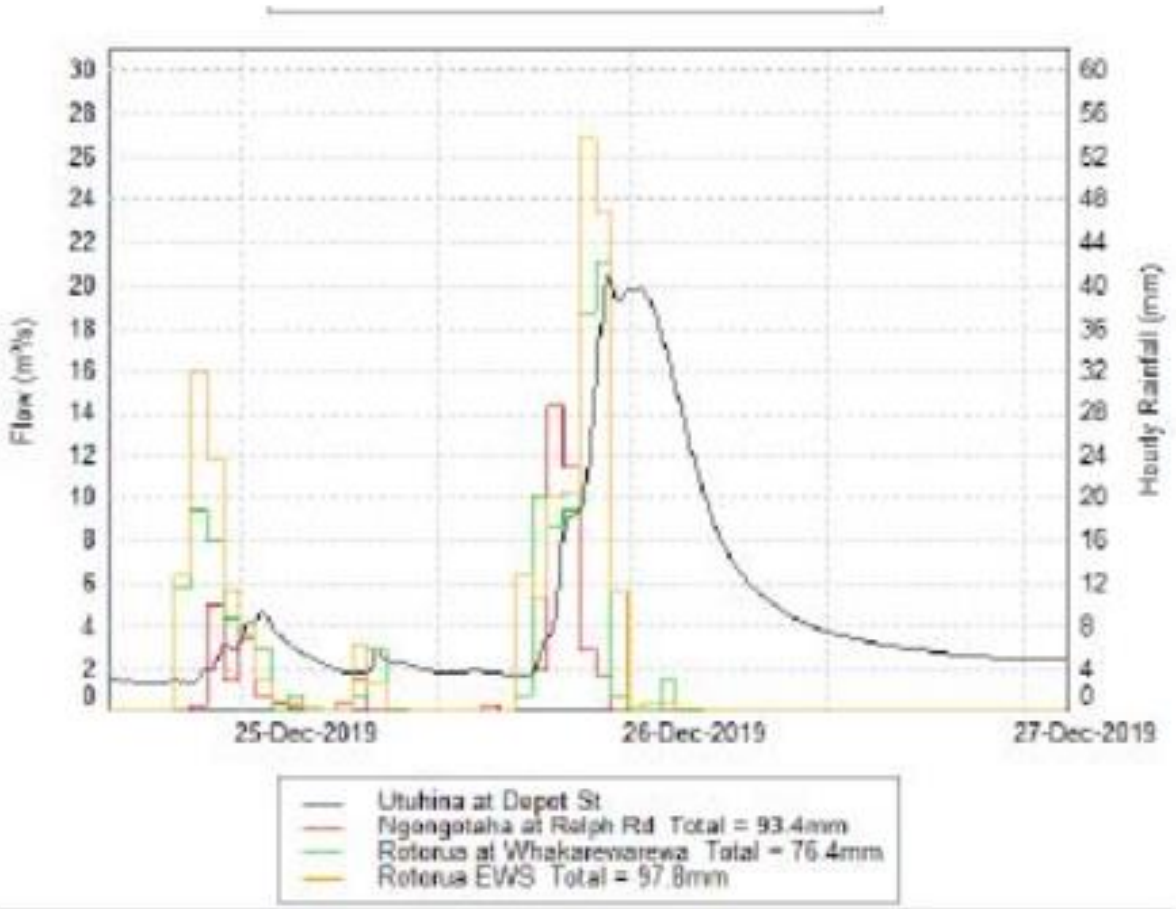


Figure 8: Rotorua Raingauges – Rainfall Event of 25-26 December 2019



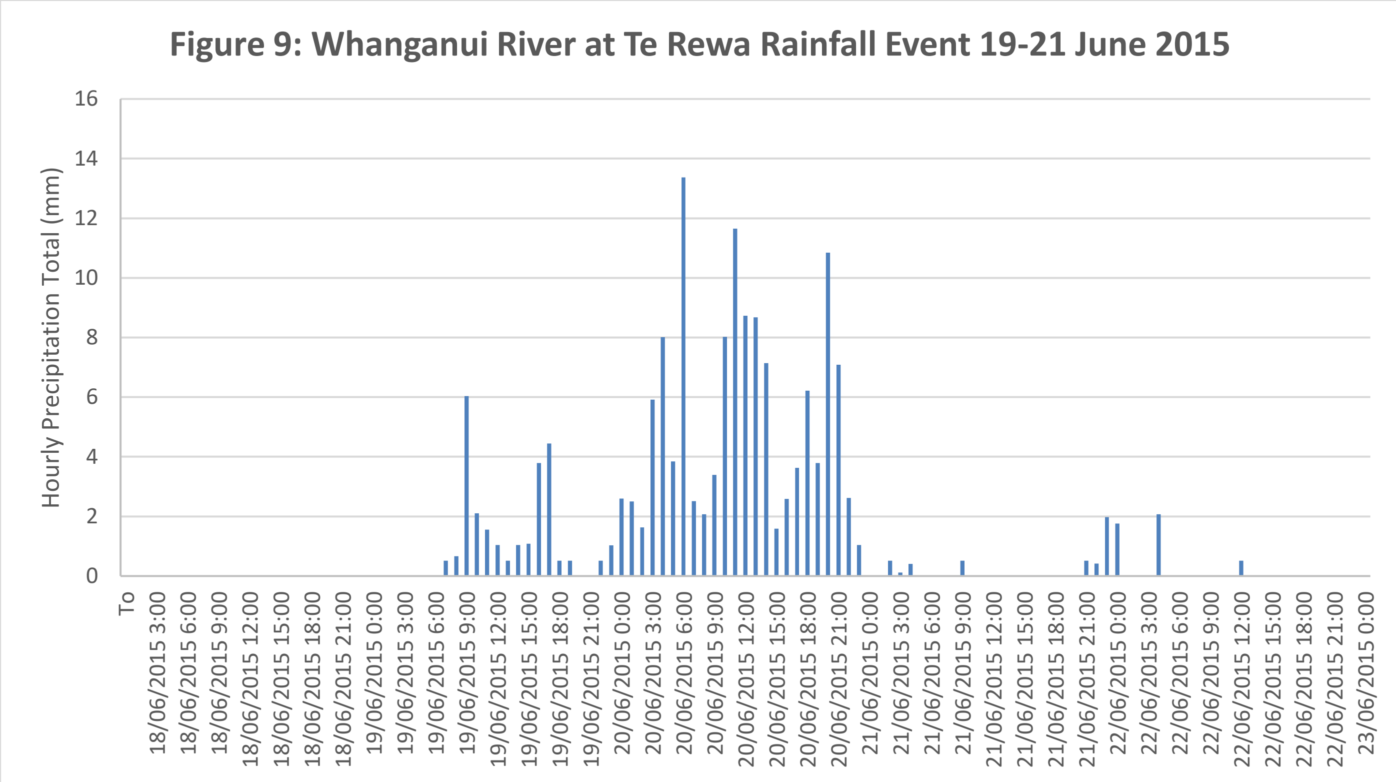


Figure 9: Whanganui River at Te Rewa Rainfall Event 19-21 June 2015
Hourly Precipitation Total (mm)
16
14
12
10
8
6
4
2
0
To
18/06/2015 3:00
18/06/2015 6:00
18/06/2015 9:00
18/06/2015 12:00
18/06/2015 15:00
18/06/2015 18:00
18/06/2015 21:00
19/06/2015 0:00
19/06/2015 3:00
19/06/2015 6:00
19/06/2015 9:00
19/06/2015 12:00
19/06/2015 15:00
19/06/2015 18:00
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