23 February 2024

Anna Madarasz-Smith
Hawke's Bay Regional Council

Dear Anna

As part of the MBIE-funded Extreme Weather Response, NIWA undertook an extreme value analysis of the flood flows that occurred at a range of river gauge sites (Figure 1) in the Hawke's Bay region during ex-tropical Cyclone Gabrielle (hereafter referred to as Cyclone Gabrielle). The purpose of the work was to understand the Cyclone Gabrielle flooding in the context of what was previously known about flood flow values in the region and to update flood statistics in the light of Cyclone Gabrielle.

This letter report reports on the estimated return periods of flooding at sites of interest and gives a brief outline of the methodology used to estimate those statistics. More detailed information on both the flood modelling and the extreme value analysis will be included in a later NIWA report.

This work required:

1. An understanding of the peak flow rate; and
2. Integration of this into the record to determine the return period of an event of this magnitude.

Due to the severity of Cyclone Gabrielle, some river gauges failed, and we do not have a measured peak flow rate for these locations. In these locations, flood models have been developed to replicate the observed flooding and flow estimates from these models have been used in the extreme value analysis. Because of the inherent uncertainty in the flow estimates, in some cases more than one value have been used to better understand the uncertainty in the results.

The systematic record (long-term monitoring information) was used, however in some locations, there are known large flood events that occurred prior to the systematic record where we have reasonable estimates of the river flow. In these locations we have also estimated the flood statistics taking into account those historical events.

Yours sincerely

Emily Lane
Principal Scientist: Hydrodynamics and Natural Hazards

National Institute of Water &
Atmospheric Research Ltd
PO Box 8602
Riccarton
Christchurch 8440

Phone +64 3 348 8987
enquiries@niwa.co.nz
www.niwa.co.nz

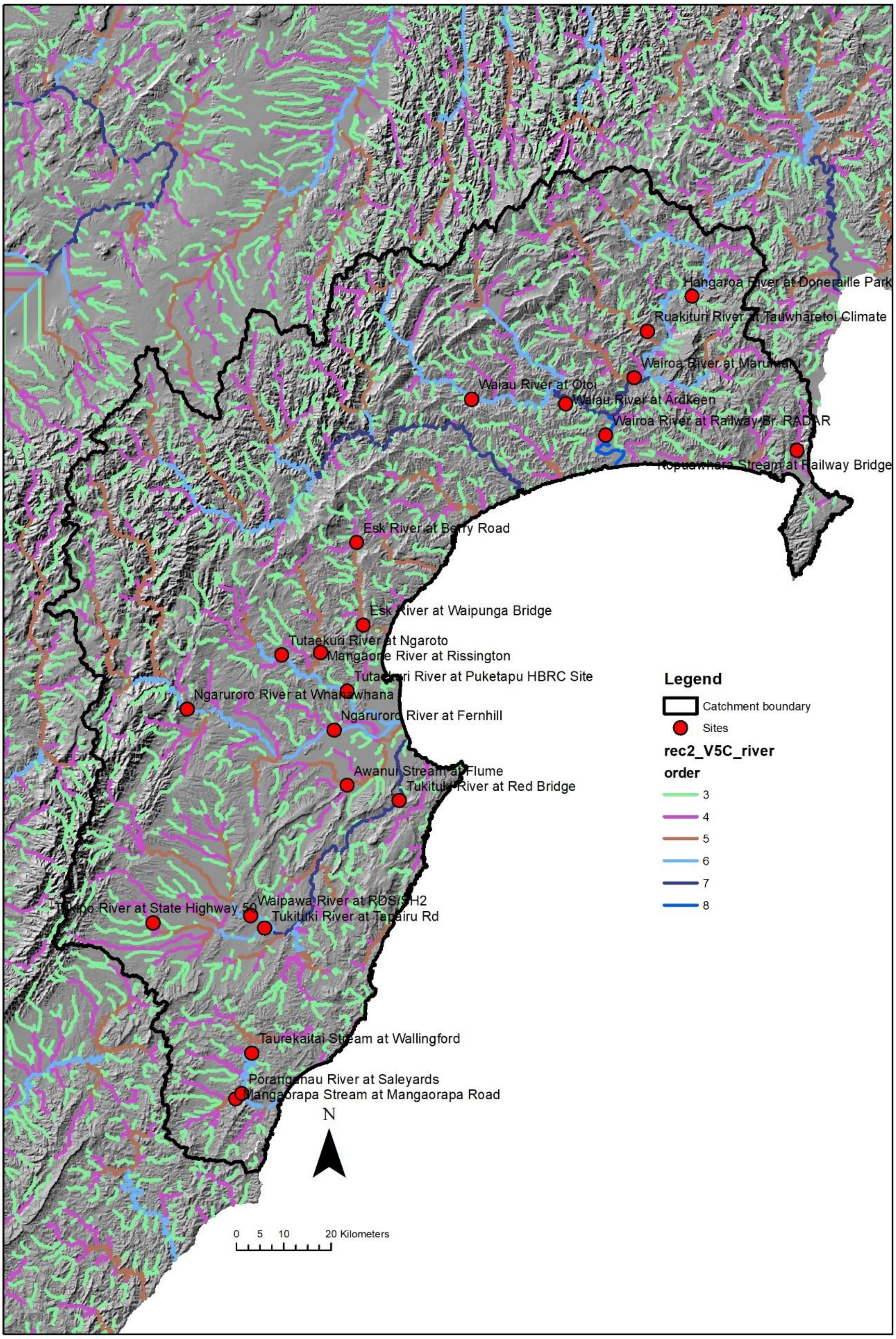

Figure 1: **Location of sites.**

Introduction

Cyclone Gabrielle was an extreme weather event and caused extensive flooding, especially in the Hawke's Bay and Tairāwhiti regions. As part of the MBIE-funded Extreme Weather Response, NIWA undertook an extreme value analysis of the flood flows that occurred at a range of river gauge sites (Figure 1) across Hawke's Bay during Cyclone Gabrielle. The purpose of the work was to understand Cyclone Gabrielle's flooding in the context of what was previously known about flood flow values in the region and to update the flood statistics in the light of this event.

Flood size at a given location is usually measured by the peak flow rate, the maximum flow rate in cubic metres per second (also known as cumecs) measured at a river gauge. This is reported as an Annual Recurrence Interval (ARI) or Return Period. This is the average time, in years, between floods of this size. It can also be expressed as, and is defined by, an Annual Exceedance Probability (AEP) which is the probability a flood that size occurs in a given year (e.g., a 100-year ARI flood has a 1% AEP). Because flood events occur randomly, just because a large flood with a high ARI has just occurred, there is no guarantee that there will not be another one in the near future. The longest flow records in Hawke's Bay are only 70 years long, many are considerably shorter. This means that we must approximate ARIs using statistical relationships (distributions) using a technique known as an extreme value analysis. At some rivers we have estimates of peak flow rates for historical floods that occurred prior to a gauge being installed and we are able to include this information in our analysis. When a large event like Cyclone Gabrielle occurs, it changes what we know about the flood flows on that river and means that we need to recalculate the ARI taking into account the new knowledge. Climate change also means that these relationships are changing over time.

At a river gauge, the water level (stage) is measured, and this is converted to a flow rate using a rating curve. This rating curve needs to be estimated by measuring flow speeds for different water levels. The severity of Cyclone Gabrielle destroyed several flow gauges. In other locations the water level was higher than any previously measured. This means that we either do not know, or have high uncertainty about, what the peak flow rates were at these locations. For these river gauges, we had to first estimate what the peak flow rate was using modelling techniques before we were able to undertake the extreme value analysis.

The next section explains the data used in this analysis. We then outline the methodology and report the ARI for each river gauge of interest in Figure 1. Two values are given. The first value represents the ARI estimated from our knowledge up until Cyclone Gabrielle and the second value shows how Cyclone Gabrielle has changed what our estimate of the ARI is at that river gauge. We then outline the uncertainties inherent in this work and the uses of these results before giving our final conclusions.

Data

Three sources of data (the best available to date) were used in the extreme value analysis of the flood flows at the sites of interest:

- the systematic record from flow gauges,
- records of historical floods and
- modelled estimates of flood flows during Cyclone Gabrielle.

The systematic record was taken from hydrological recording stations operated by Hawke's Bay Regional Council (HBRC) and the National Institute of Water and Atmospheric Research (NIWA). Annual maximum floods were extracted from the systematic record for each site. In cases where there were large gaps in the data, nearby rainfall records were used to determine whether a gap occurred during a period without high rainfall nearby, giving us confidence that the maximum flow for that year had been captured by the gauge. If there was high rainfall nearby during gap in gauge data (meaning we were not confident that the gauge had captured the maximum flow), we removed that year from the analysis.

Historical flood records were studied to identify any flow data that exists on large floods that occurred at these sites before the systematic record that could be used to increase the timeframe that the record covered.

Due to the severity of the flooding during Cyclone Gabrielle, some of the river gauges failed during the event and we do not have observed peak flood flows for these locations. There is also some uncertainty in the maximum flood flow at some sites where there was out-of-bank flow (breaches or overtopping), where water may have been backed up due to debris dams downstream, or where the rating curve has not been adequately assessed for high flows (due to the size of this event compared to previous floods). For these locations, modelled flood flows were also considered. The section below describes the process of modelling the event and extracting the flows.

For the flood flow peaks during Cyclone Gabrielle, HBRC and NIWA assessed the information available from modelling and the observations. Where there was high uncertainty in the peak flow estimate, a range of numbers were used to understand the possible ARIs. Gauging records, rating curves, rainfall runoff models, 2D hydrological models and expert opinion were all used to inform the peak flow estimates. Table 1 outlines the peak flow values, what sources were used for each site and the reasoning behind these choices. Table 2 gives the ARI results.

Historical data

Due to the systematic record being relatively short lived when considering climatic events such as large floods, information on historic events can increase the accuracy of estimated return intervals. This is because knowledge over a longer time frame can increase the rigour of flood frequency estimates.

A range of resources were used to collate historical flood information on rivers within the Hawke's Bay region (Cowie 1957, Hawke's Bay Rivers Board 1919, 1928, Hawke's Bay Catchment Board & Regional Water Board 1985, Hawke's Bay Regional Council 2004, Hawkins 1977, NIWA 2018, Williams 1985). In addition to these resources, Hawke's Bay Regional Council provided flood flow information that had been compiled in-house at the council. This information was cross-checked with the references above and additional resources that Hawke's Bay Regional Council provided to NIWA.

The target data included any information about river stage heights, estimates of peak flow discharge and anecdotal information about places where the river overflowed. Information pertaining to the above target data was compiled from all available resources into a master spreadsheet. This spreadsheet includes the sites of interest for HBRC, as well as other sites mentioned in the resources. Where evidence exists of large floods (including estimates of the peak flow rate) at the sites of interest prior to the systematic record, the extreme value analysis was undertaken that includes the historical data.

Modelling

The flood modelling for Hawke's Bay was undertaken in three parts, rainfall over the region, flood flows in the upper catchments and inundation modelling in the flood plains. Further details on this modelling will be provided in NIWA's later report on this project.

Rainfall

The rainfall was estimated in an augmented VCSN (Virtual Climate Station Network, see https://niwa.co.nz/climate/our-services/virtual-climate-stations) with a spatial resolution of 500 m × 500 m over the Hawke's Bay region and an hourly temporal resolution. This augmented VCSN dataset is based on both rain gauge data and numerical weather prediction (NWP) output. It includes HBRC and Gisborne District Council (GDC) gauge data, NIWA and MetService gauges as well as some citizen rainfall observations collated by HBRC. The gauge-based data provide reasonable point estimates of rainfall and a good representation of the temporal structure of the event but are not adequate to accurately provide high resolution spatial information. To alleviate this, NWP data from NIWA's 1.5 km grid-length forecast model used to provide a physically realistic spatial description of the event for the augmented VCSN dataset. Even though the NWP data model induced biases, it can be used to guide the interpolation process which converts the gauge observations to a gridded product. Due to the lack of observations, the results over the ocean are not reliable and outside of the GDC/HBRC regions where the gauge density is much lower, the dataset will be less accurate.

Flood flows

The flood flows were modelled over the entire Hawke's Bay region using the sub-catchment based hydrological model, TopNet (Clark et al. 2008, McMillan et al. 2016). The model combines a water balance model within each catchment with a kinematic wave routing algorithm through the river network. The K_i version of TopNet was used as research suggests this captures flood flows better than other uncalibrated model versions. Note that as TopNet is based on a network of sub-catchments, the results assume that all the water stays in the river channel and follows the path of the river network, so it does not capture out-of-banks flow or flow paths on flood plains that break the standard river network. Historical VCSN data were used to prime the model with the correct antecedent conditions at the start of the simulation. TopNet was then forced with the augmented VCSN rainfall which produced hydrographs for each sub-catchment over the event.

Flood inundation

Flood inundation on the flood plains was modelled using BG-Flood. BG-Flood (Block-adaptive, Graphics processing unit (GPU) capable, Flood model) is a numerical model for simulating shallow water hydrodynamics (SWH) on GPU using adaptive quad-tree type mesh (Bosserelle et al. 2021). The model is designed with the goal of simulating inundation from any flood driver (rainfall, river, storm surge or tsunami) on an optimised mesh that is automatically generated and refined by the model using the same Cartesian grids as forcing (i.e., for DEM, roughness, wind, rainfall). The model is open-source and publicly available at: https://github.com/CyprienBosserelle/BG_Flood.

The SWH engine is well established and has been thoroughly tested in Basilisk (e.g., Popinet 2003, Popinet 2015) and through benchmark evaluation. The model uses modern hydrostatic reconstruction to limit unrealistic flow velocity through steep topography (Buttinger-Kreuzhuber et al. 2019). BG-Flood can run on an adaptive mesh to allow higher resolution where required. This enables efficient simulations by keeping the number of nodes low while maintaining high resolution where flooding occurs.

DEMs and roughness maps for the flood plains were created from LiDAR data using GeoFabrics (Pearson et al. 2023) and incorporating extra information on flood infrastructure where available. The flood models were forced where rivers enter the domain by hydrographs taken from the TopNet modelling. The augmented VCSN rainfall was also applied over the flood plain. The sea boundary was forced with predicted storm-tide levels taken from NIWA's Environmental forecasting system (Lane & Walters 2007).

Model results were compared with flood extents estimated from aerial imagery and/or flood levels where available. Where there were differences, the sensitivity to input river hydrographs and rainfall were investigated to see if better agreement could be found. For locations of interest, water levels and velocity were extracted from cross-sections over the river and the flow was calculated from these. Because there was out-of-bank flow in many of these locations, there is some variation in the flow values depending on how wide the cross-sections were but generally we attempted to capture the entire width of water.

Other modelling has been also undertaken for specific recovery projects on several rivers and estimates of flood flows from this modelling have also been used for Tukituki at Red Bridge, Esk River at Waipunga Bridge (PDP 2023), Wairoa River at Marumaru and Waipawa River at RDS.

T+T's assessment of the peak flow in the Tūtaekurī River at Puketapu during Cyclone Gabrielle considered the following:

- the estimated surface flow velocity from a video clip at the Vicarage Road bridge site, with an adjustment factor applied to represent the cross-sectional averaged velocity
- extrapolation of the mean flow velocity as a function of stage from the gaugings on file.

Both methods indicate a possible discharge between 3300 and 4200 m3/s. Taking note also of HBRC's hydraulic model (TK_NG_CL_9.0) discharge of 4480 m^3/s, a best-estimate of approximately 4000 m^3/s in round terms was adopted, though the possible bounds are wide, from 3300 to 4500 m3/s. A peak breakout flow from the river channel upstream of Puketapu of 800 m^3/s was estimated by HBRC. A simple addition indicates a peak flow of approximately 4800 m^3/s if the breakout did not occur (Leong 2024).

Analysis of the Tukituki River flow sites was undertaken as part of a review of the Upper Tukituki Flood Control Scheme (T + T 2023). In this T+T pooled and rationalised available information from the monitored sites (principally water level hydrographs and flow gaugings on file) and took into account observed stopbank breaches, other anecdotal information and hydraulic modelling output (MIKE+ routed peak flows, water levels and timing) to either confirm or revise rated peak flow estimates for Cyclone Gabrielle. The MIKE+ model was used to model the peak flow in the Tukituki River at Red Bridge if the breakout at Walker Road did not occur.

Modelling of the flooding in Wairoa was performed for HBRC by WSP post-Cyclone Gabrielle for the purposes of land categorisation and flood risk management optioneering. Models were generated in TUFLOW and MIKE+ software packages. The report from this, 'Wairoa River Fluvial Hydraulic Model' (WSP, 2024), is currently under peer review but will be released in the near future.

Extreme value analysis

Using extreme value analysis, we assessed both the ARIs for the Cyclone Gabrielle peak flood flow at each site of interest for the systematic record as it stood prior to the event (pre-Gabrielle) and the revised ARIs taking the Cyclone Gabrielle event into account (post-Gabrielle). Where historical data of peak flood flows existed a second round of analysis was done incorporating this. Where historic information existed, this analysis was used in preference to the systematic record only. Table 2 presents these results, and the final column indicates the data used and the length of the systematic record at each location.

Based on a literature review we adopted the standard approach to flood frequency analysis (Hosking and Wallis (1997). This involves using continuous annual maximum flood peak data at a site and fitting the data with a number of statistical distributions. Peaks over an arbitrary threshold or partial duration series were not used – these are usually employed only at sites with short records because they increase the amount of data available for distribution fitting (Kuczera and Frank, 2006).

Specifically, we used the Generalised Extreme Value (GEV), Gumbel, log Pearson, log normal, and Pearson III distributions (Hosking and Wallis, 1993, Hosking and Wallis, 1997; Kotz and Nadarjah, 1999). A (four parameter) two-component extreme value distribution (TCEV) was not included because we don't have sufficient empirical evidence that two populations of flood peaks were present at any site as a result, for example, of major floods being generated by different processes from small floods or from storms coming from different directions (Connell and Pearson, 2001). It was also not fitted for single site flood frequency analysis, as this is not advisable for four parameter distributions.

L moments (Hosking and Wallis, 1997) were employed to fit all of the distributions to site data. For the purposes of illustration, a flood peak, Q_p, versus ARI, T, graph for each site was plotted using the Gringorten plotting position which is the most appropriate one for the extreme value distributions (Gumbel, GEV and TCEV distributions). ARI was used because of its familiarity to most readers rather than AEP which is often employed in technical publications. Note, however that AEP = 1/T, T in years, and T = 1/AEP defines return period and ARI.

The current work has demonstrated that the Generalized Extreme Value (GEV) distribution consistently provides a good fit, as determined both visually and through statistical goodness-of-fit tests. This finding is consistent with previous research conducted in the Hawke's Bay region (McKerchar and Pearson, 1989; Griffiths and McKerchar, 2012). These results are presented in this letter report. Results using other extreme value distributions will also be provided in the NIWA report.

Many of the distributions tested provided a sufficient fit to the data, however the GEV was identified as the preferred choice for determining the ARI for Cyclone Gabrielle (for the reasons detailed below). It is acknowledged that the GEV distribution curves upwards and may exceed the theoretical / physical catchment capacity for flooding at the higher ARIs. The 'Probable Maximum Flood' (PMF) estimate for a catchment is an upper ceiling with a very low AEP (high ARI). Between the upward curve of the GEV and a flattening off to a PMF, there will be an interim distributional relationship between flood peaks and return period, which is not the subject of this report. Therefore when higher ARIs are being considered, alternative distributions may be more appropriate.

The Generalized Extreme Value (GEV) distribution emerges as the preferred choice over alternative distributions like the Gumbel, Log Pearson, Log Normal, and Pearson III distributions for several reasons. One of the primary advantages of the GEV distribution lies in its theoretical basis as an Extreme Value distribution, applying to the (annual) maximum of a sample regardless of the underlying flood generating distribution. The statistical basis is similar to the Central Limit Theorem specifying that the Mean of a sample has a Normal distribution regardless of the underlying distribution. The GEV distribution's three parameters provides the flexibility to represent a wide range of medium flood tail behaviours. Unlike other distributions constrained by specific tail shapes, the GEV distribution can accommodate diverse tail behaviours, making it more suitable for modelling extreme events accurately. Moreover, the robustness of the GEV distribution allows it to handle both heavy-tailed and light-tailed data effectively, ensuring a good fit across various datasets with different skewness and kurtosis properties. Its ability to capture complex tail behaviours, including heavy right or left tails, further enhances its utility in modelling extreme events accurately. Empirical studies by researchers such as Hosking and Wallis (1993, 1997) and Kotz and Nadarjah (1999) have provided empirical support for the superiority of the GEV distribution in fitting extreme value data compared to other distributions. By considering these factors, researchers can confidently select the GEV distribution as the most suitable option for analysing extreme values in hydrological and climatological studies, thereby ensuring robust and accurate modelling of extreme events.

Hosking and Wallis (1997) recommend the fitting of distributions by L-moments in a 'regional' setting – by plotting the L-moment ratios L-kurtosis (t4) versus L-skewness (t3) of annual maximum series in a region. In the t3-t4 plane three-parameter distributions (e.g., GEV, log-Pearson) plot as curves and two-parameter distributions appear as dots (e.g., the Gumbel distribution is represented by the coordinates (t3=0.17, t4=0.15)). Figure 2 shows wide scatter for the HBRC L-moment ratios (as for NZ floods in Pearson 1991) and this indicates a three-parameter distribution and not the Gumbel is a suitable generating distribution of such (t3, t4) behaviour.

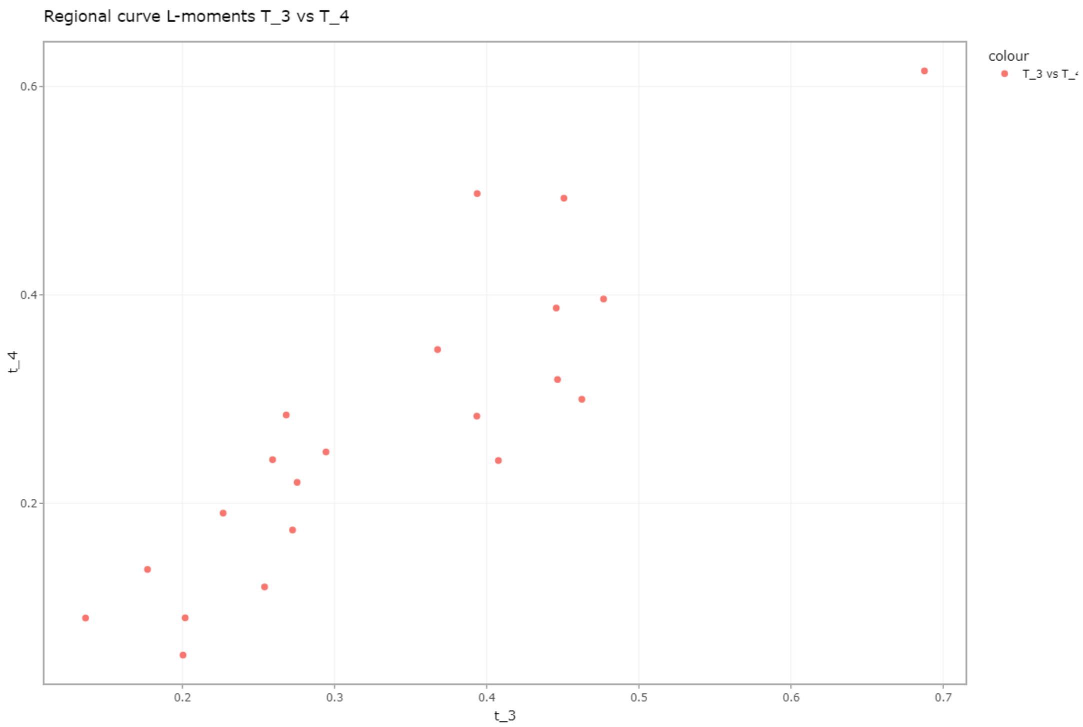

Figure 2:- HBRC L-moment ratios for 21 annual maximum series. The Gumbel distribution is represented by the coordinates (t3=0.17, t4=0.15).

Hosking and Wallis (1997 also recommend use of regional growth curves for extrapolating to high return periods (> 100 years and beyond) rather than just relying on at-site flood frequency analysis. The GEV and Kappa (4-parameter) distributions fitted to the dimensionless (divided by mean annual flood) to 21 HBRC annual maximum flood series are shown in Figure 3. The closeness of the GEV and Kappa curves shows that the GEV fit is a good representation of the HBRC regional flood frequency. The use of this curve is recommended with mean annual flood for estimation of floods with higher return periods.

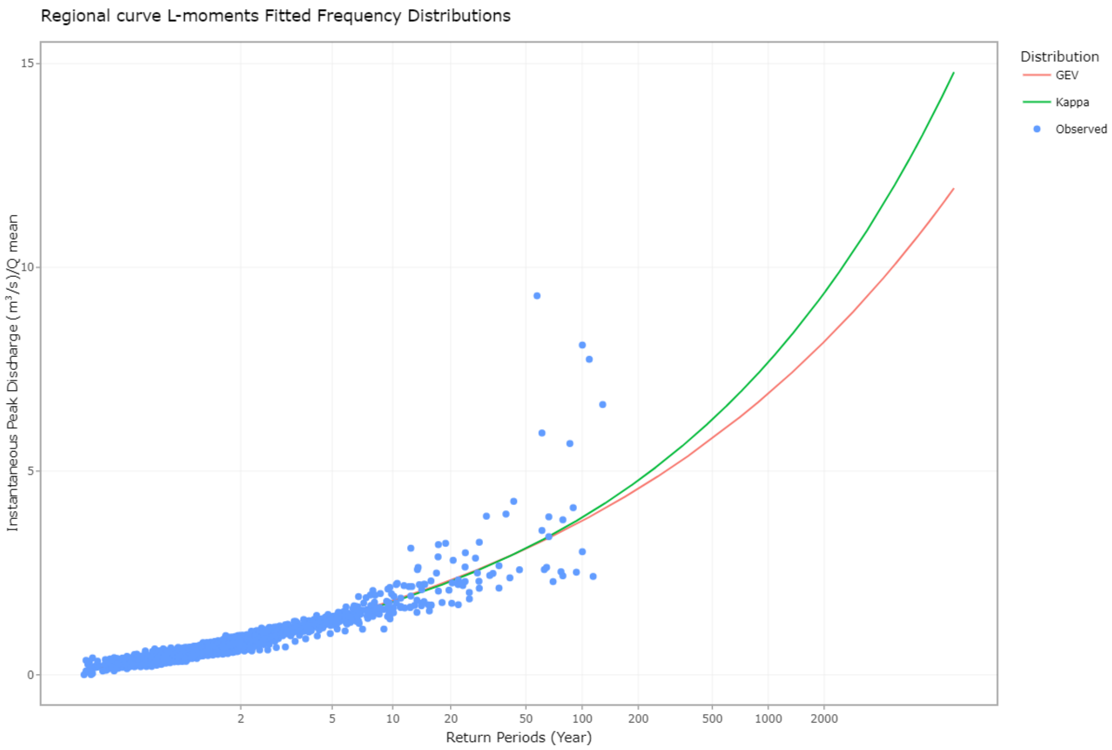

Figure 3. HBRC dimensionless (divided by mean annual flood) annual maximum flood series fitted by regional GEV and Kappa distributions.

For locations where information on large flood flows was identified in the historical record, the return period of Cyclone Gabrielle (both excluding and including Cyclone Gabrielle) taking into account these historical records, is calculated using a Bayesian Markov Chain Monte Carlo (BMCMC) inference approach to combine these historical records with the systematic ones (Neppel et al. 2010, Griffiths et al. 2017, Lucas et al. 2023). This methodology requires defining a historical period over which floods are considered and a perception threshold for flood peaks. In this analysis we are using 1893 as the start of the historical period. This choice is arbitrary and arbitrarily applied to each catchment because:

- There was a large historical flood event in 1893 across several Hawke's Bay catchments.
- It is not going too far back to have less confidence that there were other large historical peaks that occurred but were not recorded in the literature (we assume we have captured all the exceedances over the perception threshold during the historical period).
- Using the same historical period at all sites will not introduce any bias into the analysis, as long as any historical peaks over the perception threshold are recorded, and all other years were below that threshold.

The historical record ends at the start of the systematic record for each site. The perception threshold serves as a criterion for identifying and incorporating years in the historical periods when no floods occurred. The specific threshold used differs from site to site and is based on historic knowledge. This helps in acknowledging the absence of flood events during certain years and ensures that such periods are appropriately considered in our analysis. We also only consider floods in the historical periods that are greater than 80% of the largest pre-Gabrielle flood in the systemic record for that site. Again, this choice is arbitrary. The rationale behind its use is:

- The analysis focuses on events with significant impact and to align with the objectives of the project. This threshold helps filter out events that, while part of the historical record, will not impact substantially on the results of our analysis.
- Peaks over this threshold are of greater value to this study, smaller historical flood peaks are of less value.
- The systematic record could be extended by use of the smaller historical floods that are close to the start of the systematic record. But overall, the systematic records are of good length for analysis, and the use of the historical floods is to see if there is any useful frequency-magnitude information over a longer time duration and for the higher magnitude historical flood peak events that can be incorporated into the analysis.

More detailed information on this methodology will be provided in NIWA's later report.

Table 1. Sources of Cyclone Gabrielle peak flow estimates and reasons why those values were chosen.

Site & Site number	Cyclone Gabrielle Peak Flow Estimate (m3/s)	Methodology used to calculate estimates	Reason value was chosen
Tūtaekurī River at Puketapu 23032	4,800	BG Flood Glass Wall	The gauge failed during the event, and therefore the peak flow was estimated using BG-Flood. The BG-Flood glass wall model estimates the flow that would have occurred if water had not been lost through breaches or overtopping. T&T modelling corroborates this value.
Mangaone River at Rissington 23019	1,393 1,610	Rated flow gauge TopNet	Although the gauge failed during the event, the peak was captured. There is, however, uncertainty in the gauging due to factors such as out of channel flow, log jams and other downstream debris. Therefore, the lower value is considered

Site & Site number	Cyclone Gabrielle Peak Flow Estimate (m3/s)	Methodology used to calculate estimates	Reason value was chosen
			the lower estimate of peak flow, and the TopNet estimate is an upper bound.
Ngaruroro River at Fernhill 23102	5,398 6,000	Rated flow gauge TopNet	The gauge measured the full event, however there was a breach upstream of the gauge. The TopNet estimate takes into account that extra flow.
Ngaruroro River at Whanawhana 23103	1,012	Rated flow gauge	The gauge measured the full event. HBRC has confidence in the rating.
Waipawa River at RDS 23235	1,810	T&T Modelling	The gauge measured the event but modelling from T&T suggest that the rated flow was too high. This is likely due to the event exceeding the top of the rating, and therefore the modelled estimate is a more appropriate peak flow value.
Tukituki River at Tapairu Rd 23207	1,805	Rated flow gauge	The gauge measured the full event. HBRC has confidence in this rating.
Tukituki River at Red Bridge 23201	4,320	T&T Modelling	The gauge measured the full event. However, some water was diverted from the river into a wetland area. The value given here is the rated flow plus an estimate of the diverted flow. This approximates what the flow might have been without the diversion.
Esk River at Waipunga Bridge 22802	2,175	PDP Modelling	The gauge failed at 2,006m^3/s before the peak flow occurred. This estimate comes from PDP modelling of the catchment. There was also a large amount of sediment that came down in this catchment which complicates these results.
Esk River at Berry Rd 22809	350	TopNet	The gauge failed at 111 m^3/s and did not capture the peak. This value is thought to be a better estimate of the peak flow.
Wairoa River at Marumaru 21401	4,100	WSP Modelling	The rated flow peaked at 4,962m^3/s, however modelling by WSP suggests there is an issue with the rating for this level of flow and that this value is more appropriate.
Waiau River at Ardkeen 21493	1,656	Rated flow gauge	The gauge measured the full event. HBRC has confidence in this rating.
Waiau River at Otoi 21409	838	Rated flow gauge	The gauge measured the full event. HBRC has confidence in this rating.
Hangaroa River at Doneraille Park 21437	2,070	Rated from measured flood depth	Flood debris was 2 metres higher than gauged level. This is the rated value based on that level.
Ruakituri River at Tauwharetoi 21432	998	Rated flow gauge	The gauge measured the full event. HBRC has confidence in this rating.
Taurekaitai Stream at Wallingford 24325	659	Rated flow gauge	The gauge measured the full event. HBRC has confidence in this rating.
Mangaorapa Stream at Mangaorapa Rd 24304	690	BG Flood	The gauge failed during the event at 421 m^3/s. This value represents our best estimate of the peak flow using BG-Flood.

Site & Site number	Cyclone Gabrielle Peak Flow Estimate (m3/s)	Methodology used to calculate estimates	Reason value was chosen
Pōrangahau at Saleyards 24301	1,590	BG Flood	The gauge failed during the event. This value represents our best estimate of the peak flow using BG-Flood.
Tukipo River at SH50 (Punawai) 23220	561	Rated flow gauge	The gauge measured the full event. There are some suggestions that the rating may overestimate the peak flow, but this is the best estimate currently available.
Kopuawhara Stream at Railway Bridge 20101	176	Rated flow gauge	The gauge measured the full event. HBRC has confidence in this rating.
Awanui Stream at Flume 1123148	38	Rated flow gauge	The gauge measured the full event. HBRC has confidence in this rating.

Table 2. ARI for the peak flow values as estimated pre-Gabrielle and post-Gabrielle, as well as the data (systematic and potentially historical) that was used in the estimation. The shaded sites are locations where the uncertainty in the ARIs is especially high due to the size of the event and the shorter record lengths, see uncertainty section for details.

Site & Site number	Flow estimate	ARI		Data (and length of systematic record)
	(m³/s)	Pre Gabrielle	Post Gabrielle	
Tūtaekurī River at Puketapu 23032	4,800	980	400	Systematic (1968-2023) and historical
Mangaone River at Rissington 23019	1393 1,610	>1,000 >1,000	400 550	Systematic (1990-2023) and historical
Ngaruroro River at Fernhill 23102	5398 6,000	710 >1,000	400 480	Systematic (1952-2023) and historical
Ngaruroro River at Whanawhana 23103	1,012	120	70	Systematic (1960-2023)
Waipawa River at RDS 23235	1,810	>1,000	120	Systematic (1987-2023)
Tukituki River at Tapairu Rd 23207	1,805	160	70	Systematic (1987-2023)
Tukituki River at Red Bridge 23201	4,320	80	60	Systematic (1968-2023) and historical
Esk River at Waipunga Bridge 22802	2,175	220	180	Systematic (1963-2023) and historical
Esk River at Berry Rd 22809	350	550	120	Systematic (1992-2023)
Wairoa River at Marumaru 21401	4,100	250	120	Systematic (1980-2023) and historical
Waiau River at Ardkeen 21493	1,656	50	40	Systematic (1988-2023) and historical
Waiau River at Otoi 21409	838	30	30	Systematic (1972-2023)
Hangaroa River at Doneraille Park 21437	2,070	420	220	Systematic (1974-2023) and historical
Ruakituri River at Tauwharetoi 21432	998	50	40	Systematic (2013-2023) and historical

Site & Site number	Flow estimate (m³/s)	ARI Pre Gabrielle	Post Gabrielle	Data (and length of systematic record)
Taurekaitai Stream at Wallingford 24325	659	60	50	Systematic (1980-2023)
Mangaorapa Stream at Mangaorapa Rd 24304	690	>1,000	110	Systematic (2000-2023)
Pōrangahau River at Saleyards 24301	1,590	>1,000	80	Systematic (2009-2023)
Tukipo River at SH50 (Punawai) 23220	561	170	90	Systematic (1976-2023)
Kopuawhara Stream at Railway Bridge 20101	176	4	4	Systematic (1981-2023)
Awanui Stream at Flume 1123148	38	50	30	Systematic (1989-2023)

Overview

The results of the extreme value analysis show an ARI of 400 to 500 years in the Heretaunga Plains region (specifically the Tūtaekuri and Ngaruroro Rivers), which shows that this was a very extreme event. In many of these locations, prior to Cyclone Gabrielle these events would have been assessed with an ARI of around 1,000 years or higher. In other locations, such as the Esk Valley, Wairoa and Hangaroa Rivers and Mangaorapa Stream it has a return period of 100-200 years. In other locations it was still a significant event but with an ARI of less than 100 years.

Uncertainty

The flooding that occurred in Hawke's Bay due to Cyclone Gabrielle was extensive. We only have rainfall records at a finite number of gauge sites and the high winds that occurred during the event may mean that some of these gauges under reported the total rainfall (due to rain falling at an angle due to the wind). In many locations there was considerable sediment and debris in the flood water and in some locations (notably the Esk Valley) considerable amounts of this sediment were deposited during the flood. Debris build-up, especially around bridges, may have caused damming which may have backed up water upstream. If these dams burst, they also may have caused surges down the river. Stopbanks were overtopped and breached.

All of this complexity leads to uncertainty in the estimated flow peaks. Furthermore, at many of these sites, Cyclone Gabrielle represents the largest flood that has occurred in the systematic record and often also in the historical record. This can mean there is uncertainty in the rating curve at the gauge. In these locations, there is large uncertainty in the extreme values analysis. The lengths of the systematic records range from 30–70 years. The historical record increases the record length to 130 years but has its own uncertainty associated with it because we are relying on historical estimates of the flood flows. In several locations, (Waipawa at RDS, Mangaorapa Stream at Mangaorapa Rd and Pōrangahau River at Saleyards – shaded blue in Table 2), the systematic records are relatively short, and the event is considerably larger than any previously recorded at those locations. Because of this, the uncertainty in these ARIs is especially high.

Severe ex-tropical cyclones only reach New Zealand periodically, but often cause extreme flooding when they do. Because they occur less frequently than ordinary rainfall events, we have less understanding of the statistics of their occurrence, making it vital to learn from Cyclone Gabrielle. Sites where the ARI is greater than 100 years will have considerable uncertainty in the exact values of these estimates, but regardless, these events represent rare and severe floods in those locations. The use of a regional TCEV distribution may be useful for describing Hawke's Bay flooding in future.

The effects of climate change are expected to also affect rainfall intensity and the occurrence or intensity of ex-tropical cyclones reaching New Zealand. These effects could change the ARI of these flood peaks in the future. The reported values, however, represent our current best estimates of the ARIs of the flood peaks that occurred during Cyclone Gabrielle.

Use of these results

These results represent our best estimates of the ARIs for the flooding caused by Cyclone Gabrielle at river gauges around Hawke's Bay. Continuing study of the event may lead to more refined estimates of peak flows at these gauges and future events could lead to further refinement of the results. These results put the event into context and show how Cyclone Gabrielle has changed our understanding of flooding in Hawke's Bay.

While the GEV distribution used in this analysis provides a robust estimate of the ARIs that occurred in this event and of the ARIs for smaller interpolated events, its shape means that extrapolating from it for very high ARIs would likely overestimate the expected peak flows. When higher ARI flood estimates are required, it is recommended to undertake further site-specific analysis. The dataset provided by this work will provide a robust starting point for that analysis.

Conclusion

Cyclone Gabrielle represents a very severe flood event over the entire Hawke's Bay region and beyond. This letter report gives estimates of the ARIs for sites of interest in the Hawke's Bay region. In many locations, especially around the Heretaunga Plains, this is the largest flood in the systematic and historical record and has an estimated return period of over several hundred years. There is a full technical report to follow this letter report.

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