Cyclone Reinsurance Pool – Determination of Cyclone Related Flood Proportions

Australian Reinsurance Pool Corporation

May 2022

finity

13 May 2022

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Dear Chris

Cyclone Reinsurance Pool – Determination of Cyclone Related Flood Proportions

We are pleased to present our report outlining the process used to determine the proportion of fluvial (riverine) flooding attributable to cyclone events covered by the Cyclone Reinsurance Pool.

We understand that this report will be shared with relevant parties, including insurers which may be covered by the pool.

Yours sincerely

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Certified Catastrophe Risk Management Professional

Appendices

1 Background

Government has passed the Treasury Laws Amendment (Cyclone and Flood Damage Reinsurance Pool) Act 2022 (and associated regulations) through Parliament on 30 March 2022 (the Act).

Under the Act, ARPC will be the operator of the Cyclone Reinsurance Pool (CRP). Among many other things, ARPC determines the premiums that the CRP will charge to insurers for the reinsurance it provides.

Section 8C of the Act defines eligible losses to be those which arise from a cyclone event. Losses are described in three categories:

1. Wind, rain, rainwater or rainwater runoff.
2. Storm surge.
3. Flood.

The draft regulation which accompanies the legislation further defines cyclones, including that the cyclone claim period closes 48 hours after the cyclone ends.

ARPC will develop CRP premiums which reflect the CRP's exposure to loss as defined in the legislation and regulations. ARPC will do this by implementing a rating algorithm which provides rates and relativities for wind, surge and flood consistent with the definitions.

2 Scope and purpose of this report

Flooding can be split into two broad categories:

- ***Pluvial flooding*** (incorporating surface flooding and flash flooding) can occur anywhere high rainfall occurs, such as the path of a cyclone. This type of flooding typically occurs at or near the time the cyclone passes over a location. This type of flooding will be allowed for in the CRP's wind premiums.
- ***Fluvial flooding*** (riverine) occurs when water in a river, lake or other water body overflows onto the surrounding banks and land. Fluvial flooding can occur some distance away and after some time from the original cyclone event, as water can take time to move downstream. The CRP covers fluvial flooding occurring within 48 hours after a cyclone has ceased. This type of flooding will be allowed for in the CRP's flood premiums.

The CRP will cover pluvial flooding due to cyclones (subject to the 48 hour limit) but not pluvial flooding due to storm. Thus, insurers will also need to split their premiums for pluvial flood arising from a cyclone, however it is covered. This allocation is beyond the scope of this report and will not be further discussed.

This report is designed to provide information about the process followed by Finity to allocate expected fluvial (riverine) flood losses between those covered by the CRP and those which are not. It will provide a summary of relevant research, studies and the methodology which was used to develop the allocation. The final factors reflecting this allocation were used in the determination of CRP flood premiums and are presented as Appendix A of this report.

ARPC will also be producing other materials which will summarise the overall CRP premium development process. This report will be limited to the specific issue of the cyclone and non-cyclone allocation of fluvial flooding.

The information in this report is being shared with insurers to assist in planning for CRP implementation. Please refer to the reliances and limitations for details on the limited basis this report is being shared.

3 Relevance for insurers participating in the CRP

Insurers covered by the CRP will need to adjust their prices to reflect the replacement of private reinsurance and retained flood exposure with that afforded by the CRP. As flooding not caused by a cyclone or cyclone related flooding more than 48 hours after the end of an event will be retained by insurers (and relevant reinsurance programs), they will need to determine what proportion of their expected flood claims costs are attributable to cyclone.

The CRP premium pool includes cyclone caused flooding losses, and consequently the CRP premium rates charge premiums for cyclone related flooding. Ultimately for consumers, the impact of the CRP depends on what insurers continue to charge for non-cyclone flood.

Therefore, it is important for both insurers and the CRP that there is a fair allocation of flooding between cyclone related (as covered by the CRP) and non-cyclone related. Ultimately, this means that savings to consumers can be realised while insurers price fairly for the non-cyclone related flooding risk that they retain.

4 Challenges with splitting flood into cyclone and non-cyclone

Catastrophe models which include flood typically do not distinguish between the source of flooding (i.e. whether it is cyclonic or non-cyclonic)[1].

Tropical cyclone ("cyclone") and severe convective storm ("storm") catastrophe models have typically focused on wind and water ingress damage for properties, with some implicit allowance for pluvial flooding.

Flood models cover fluvial flooding, but do not generally provide information on what proportion is cyclone related. Reflecting the modelling, insurers do not commonly distinguish between the source of flood when pricing for fluvial flooding.

A further complication unique to the CRP is the application of a 48 hour window for losses to occur after the end of an event. We are not aware of any commercially available models which allocate losses by time following the end of an event. In the market there are practical limits on claim periods resulting from the application of event definitions and hours clauses in reinsurance contracts, which allow for recoveries on losses occurring during periods such as 72 hours for wind and 168 hours for flood (there exist a range of hours clauses in the market). Since catastrophe models are typically calibrated using post event surveys of claim experience, such clauses will be indirectly reflected in models.

The share of overall fluvial flooding due to cyclone and non-cyclone is expected to vary by location, since the proportion of underlying events (tropical cyclones vs. monsoonal troughs or other weather systems) which generate sufficient precipitation to cause flooding varies, with a higher proportion of loss being cyclone in coastal locations at lower latitudes (e.g., closer to the equator) than elsewhere.

In the following sections we discuss the methodology adopted for this task and the data sources used.

5 Methodology

There are no well-established methods of allocating fluvial flooding to cyclone and non-cyclone components. To inform its role in the setting the CRP premium pool and also to assist insurers in determining the amount of non-cyclone related flooding they may retain, ARPC commissioned the following two studies from Risk Frontiers to estimate the proportion of flood caused by cyclone:

[1] As discussed below, we have incorporated the outputs from the COMBUS catastrophe model, which does split flooding by source.

- *Literature review of historical cyclone events:* A review of past cyclone events since 1966 and their associated flooding losses (estimated).
- *Basin discharge study:* A study of historical river basin water gauges over the past 111 years identifying incidences of elevated water flows and those associated with nearby cyclone tracks.

These studies are discussed in turn below.

We have also reviewed the modelled estimate of cyclone related flooding from the COMBUS catastrophe model. The COMBUS model estimates fluvial flood by whether it is caused by tropical cyclones, low pressure systems or synoptic storms[2].

5.1 Risk Frontiers Literature Review

Risk Frontiers undertook a literature review of post-1966 cyclone events involving flood related loss (there were 68 cyclones in the study, 43 which were identified as having a flooding component). A proportion of each cyclone's claim costs was attributed to fluvial flood damage. The contribution of flood loss for each event was assessed using a combination of Risk Frontiers' PerilsAus database, spatial analysis (i.e. if the flood loss was clearly separated from other damage), or expert judgment from the hazard description. Risk Frontiers approach considers restricting fluvial flooding losses to the CRP's 48 hour post cyclone event time limit

The Risk Frontiers literature study report is attached as Appendix B.

5.2 Risk Frontiers Basin Study

Risk Frontiers was engaged by ARPC to study historical river basin discharge events and to identify which of these events were likely caused by cyclone. At a high level, the approach can be described as follows:

- Daily rainfall data (collected for a gridded geographical map of Australia) and basin runoff data were collected for 1911 to 2021 for 134 river basins in cyclone prone areas. Peak river discharge levels were used as a proxy for flooding events. The Risk Frontiers report notes that peak discharge does not necessarily result in flooding. Actual flooding events will depend on flood mitigation, ability for rivers to store water, etc., which were not investigated as part of this project.
- (Proxy) flooding events are attributed to a cyclone event if the catchment falls within 150km of a cyclone track (over the past 111 years) within a 14 day window.
- To estimate the effect of the 48 hour post cyclone event window, Risk Frontiers recorded the maximum value of each basin discharge within the 48 hour coverage period. This means for river basin that are located outside of cyclone areas, given it will take time for downstream flooding to occur from cyclonic floods to reach these basins, discharge events are measured within the 48 hour coverage window only, resulting in a lower proportions of TC related flood.

The Risk Frontiers basin discharge report is attached as Appendix C.

Due to the small number of high basin discharge events (i.e. less frequent events at higher return periods) for any individual river basin, we have grouped basins into broader geographical regions to estimate proportion of cyclone related flooding at the 1 in 50 level. Differences at a basin level were based on observed 1-in-10 and 1-in-20 year return period events.

[2] ARPC evaluated and procured a range of catastrophe models for the purpose of informing CRP premium rates. COMBUS was one of these models adopted.

The basin study potentially understates the level of cyclone related flooding. There is limited data at high ARIs (rarer events), where cyclone events are likely to contribute to a higher proportion of flooding. The approach relies low ARI observations, which will show a lower cyclone percentage.

6 Results

Table 6.1 summarises the results of the Risk Frontiers literature study. The estimated cyclone flood losses were compared to estimated total flood losses over the same period by geographical regions, sourced from the ICA catastrophe list. This analysis was summarised for all cyclone events post-1966 and post-2000.

Table 6.1 – Results of Risk Frontiers Literature Study

	1966 to 2019			2000 to 2019		
Region	Cyclone related flood AAL[1]	Flood AAL[2]	% cyclone flood	Cyclone related flood AAL[1]	Flood AAL[2]	% cyclone flood
Far North QLD	103.4	137.2	75%	111.7	200.3	56%
South West QLD	6.8	11.2	61%	17.8	29.3	61%
South East QLD	49.5	131.8	38%	5.2	220.9	2%
NSW	3.0	51.3	6%	0.0	30.8	0%
NT	4.7	6.0	78%	0.5	0.5	100%
SA	0.0	1.3	0%	0.0	3.4	0%
TAS	0.0	1.8	0%	0.0	4.7	0%
VIC	0.0	18.8	0%	0.0	18.9	0%
WA	5.4	6.8	79%	2.3	5.4	42%
Total	172.8	366.3	47%	137.4	514.2	27%

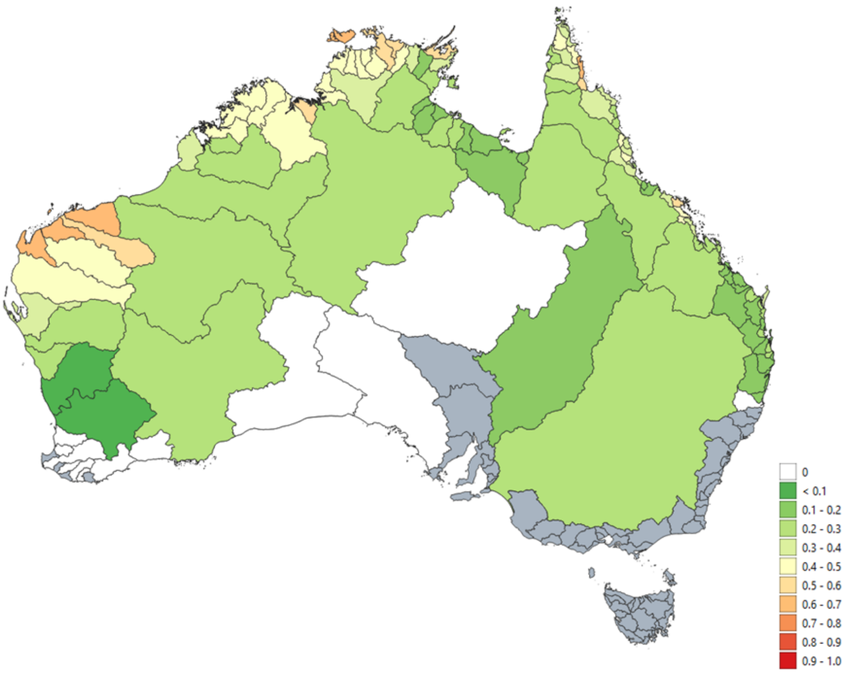
[1] Risk Frontiers Literature Study

[2] ICA catastrophe list

This study will overstate the extent of flooding damage as it assumes all costs are within 48 hours, which is not always true.

Figure 6.1 summarises the results for the selected cyclonic flood proportions by basin catchment area. Note that Finity adjusted the basin level results by smoothing across neighbouring catchments.

Figure 6.1 – Proportion of cyclone related flood by basement catchment area

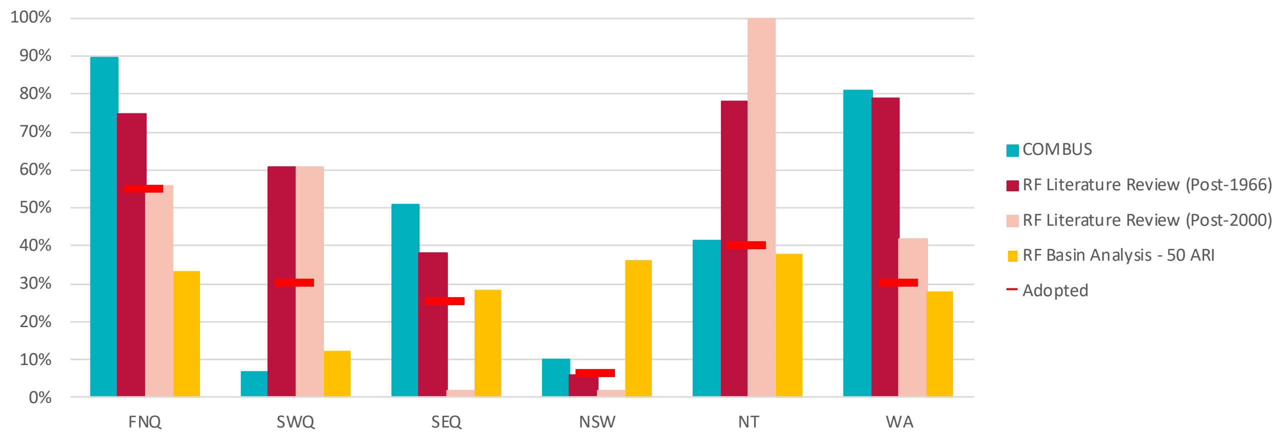


The basin analysis has been adjusted for larger basins such as the Murray Darling system, where estimates of flooding 48 hours following cessation of a cyclone would depend on the location within the large basin. In our estimates of cyclone related flood, we have assumed that cyclone related flooding reduces in these large catchments moving further away from the predominant cyclone regions.

6.1 Comparing cyclone flooding estimates

We have compared the estimates from each of Risk Frontiers studies by region with cyclone related flooding estimates from the COMBUS catastrophe model. Figure 6.2 summarises the results of each information source and the selected proportion for the purposes of this report. This is presented on a broader regional level to match Risk Frontiers literature reviews.

Figure 6.2 – Comparison of estimated proportion of flood losses caused by cyclones



No single method produces what we would consider a well-tested and independently verified estimate of cyclone related flooding, such is the newness of this for the Australian market. This is area that would benefit from further research. Table 6.2 compares the methods we have reviewed for this Report.

Table 6.2 – Comparison of methods used to estimate cyclone related flooding

Approach	Pros	Cons
Catastrophe model (COMBUS)	A catastrophe model that does distinguish between causes of flooding.	The results coming from the model appear to be at the extremes – highest in some areas, lowest in others. Estimates of the proportion of cyclone related flooding will depend on the quality of the non-cyclone related flooding estimate. The model does not properly model the hydrological processes.
RF literature studies (1966 – now)	Somewhat long history, good for studies of flooding events that require long time horizons. Based on observed events – real data.	Older data will clearly not be as reliable as more recent data. Only 43 cyclone events with flooding identified. All flooding assumed to be within 48 hours. Flood loss for each event mostly from expert judgement, less so on real claims data.

Approach	Pros	Cons
RF literature studies (2000 – now)	Based on more reliable historical records.	Short time horizon, so the experience is heavily influenced by fewer than 20 cyclones in the historical event dataset.
RF Basin analysis (adjusted)	Based on reliable historical records that have been kept over a long time period. 111 years of data.	Basin discharge events do not necessarily result in flooding.

This leaves us with a range of estimates. As noted above, insurers will need to come up with their own assessment of the proportion of flood caused by cyclone when adjusting their prices.

Appendix A shows the selected proportion of flooding caused by cyclone by CRESTA.

6.2 Allowing for flooding occurring within 48 hours

The CRP will cover flooding that occurs 48 hours following the end of the declared cyclone. Models of flooding losses do not typically identify the timing of when losses occur[3], and therefore do not provide a measure of flooding that might be incorporated within the CRP's coverage definition.

The above estimates approximate the 48 hour time restriction in the following ways:

- The COMBUS model only captures flooding occurring in the same region as the cyclone wind risk. As flooding outside of the cyclone affected region is not captured, estimated flooding losses are not likely to include damage occurring after 48 hours.
- In the Literature Review, Risk Frontiers has considered event durations to estimate flooding losses occurring within 48 hours. This was based on date of claim in Risk Frontiers data.
- In the Basin Study, Risk Frontiers measured maximum water levels occurring within 48 hours of a cyclone.

Additionally, because some river basin systems are quite large, Finity reduced the proportion of cyclone related flooding for areas further away from the main cyclone regions (i.e. the cyclone related flooding is lower as one moves inland or southward). This is to approximate the 48 hour flood timeframe to reflect the time taken for water to move downstream.

7 Uncertainties and opportunities for further refinement

As outlined in previous sections, segregating fluvial flood losses into cyclone (limited to 48 hours) and non-cyclone portions has not previously been rigorously examined in academic literature nor has it been explicitly allowed for in most commercially available catastrophe models.

We have relied upon a catastrophe model and studies prepared by Risk Frontiers, each producing an estimate of relevant allocation of fluvial flooding between the components covered by the CRP and that which will be retained by insurers. There is significant uncertainty in the available information. Catastrophe models are simplifications of complex natural weather processes, the interaction with building damage and finally the estimate insurance losses. Catastrophe models differ in how this is achieved, but even the most sophisticated

[3] Current catastrophe reinsurance programs typically have a 168 hour clause for flooding events. It is generally assumed that modelled flooding losses fall within this timeframe.

models cannot incorporate all the variables that occur in real life. Instead, catastrophe models are better considered as a tool to assist the CRP and its management. The Risk Frontiers studies (attached) discuss the limitations of their analysis.

We consider the results presented in Appendix A to be a reasonable estimate of the proportion of fluvial flooding expected to be caused by cyclones given the available information and time available to analyse it. Other experts reviewing the same information or who have access to additional studies might come to a different conclusion.

We believe that there is a significant opportunity for ARPC to further refine these estimates by:

- Undertaking additional studies, potentially including experience from other countries.
- Collecting detailed claim information from insurers on past cyclone events.
- Studying future losses when they occur, importantly by collecting data specifically designed for this purpose.
- Engaging with a wider cohort of catastrophe modelers and academics to gather additional insights and analysis.

8 Reliances and Limitations

This report and the analysis contained therein summarises work completed solely for ARPC for the purposes of determining the CRP premium. This summary report has been provided to insurers to assist with their own analysis in regards to cyclone related flooding.

Insurers, or any other third party, should recognise that the furnishing of this report is not a substitute for their own due diligence and should place no reliance on this report or the data contained herein which would result in the creation of any duty or liability by Finity to the third party.

We have relied on the findings of Risk Frontiers in the two reports commissioned by ARPC for the purpose of informing this work. We have not independently verified Risk Frontiers' findings nor have we independently validated its data or research. We have reviewed the findings for reasonableness and suitability for the purpose of this report.

We have formed our views based on the current environment and what we know today. If future circumstances change, it is possible that our findings may not prove to be correct.

The underlying exhibits and attachments contained in our Report are an integral part of this report and should be considered in order to place our report in its appropriate context. We have prepared this report in conformity with its intended use by persons technically competent in insurance matters. Judgements as to the conclusions drawn in this report should be made only after considering the report in its entirety.

We remain available to answer any questions which may arise regarding our report and conclusions. We assume that users of this report will seek such explanation and/or amplification of any portion of the report that is not clear.

Appendices

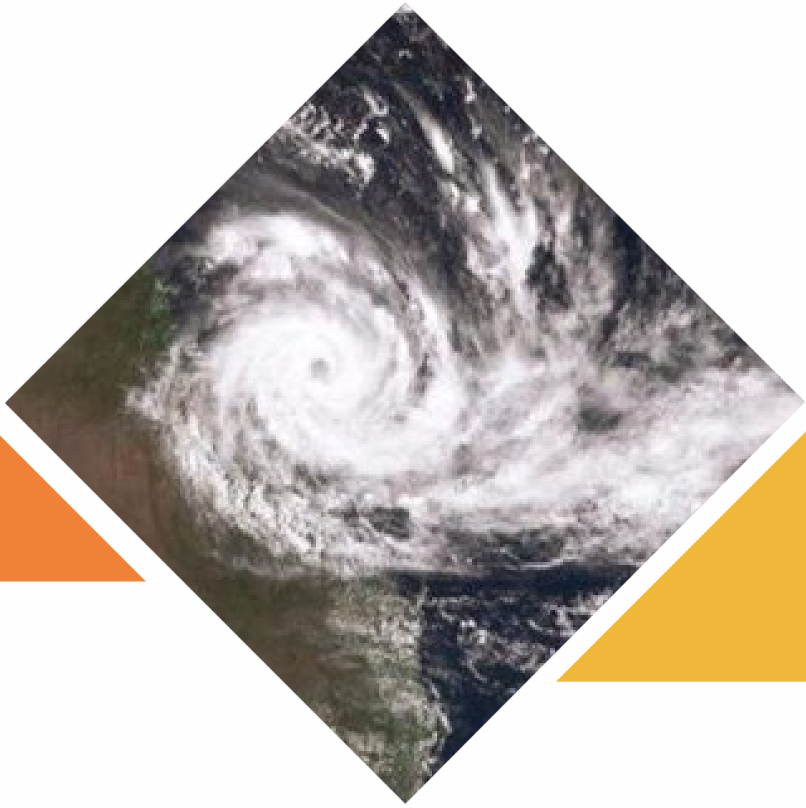
A Proportion of flood caused by cyclone by CRESTA

CRESTA	State	Name	% Cyclone flood
1	QLD	Gold Coast	21%
2	QLD	Brisbane	23%
3	QLD	Sunshine Coast	27%
4	QLD	Wide Bay	30%
5	QLD	Rockhampton	40%
6	QLD	Maryborough	43%
7	QLD	Mackay	50%
8	QLD	Proserpine and Offshore Islands	75%
9	QLD	Townsville	50%
10	QLD	Ingham	67%
11	QLD	Cairns	68%
12	QLD	Cape York	43%
13	QLD	Fair Cape	52%
14	QLD	Gulf	38%
15	QLD	Inland QLD	29%
16	NT	North NT	70%
17	NT	Darwin	70%
18	NT	Remainder NT	19%
19	WA	Kununurra-Broome	75%
20	WA	Pilbara	75%
21	WA	Geraldton Central Coast	45%
22	WA	Perth	38%
23	WA	Albany-Bunbury	16%
24	WA	Remainder WA	13%
25	SA	Remainder SA	0%
26	SA	East Eyre and York Peninsulas	0%
27	SA	Adelaide	0%
28	SA	Adelaide Hills and South coast	0%
29	TAS	Tasmania	0%
30	VIC	Western Victoria	0%
31	VIC	South-West Victoria	0%
32	VIC	South-East Victoria	0%
33	VIC	Melbourne	0%
34	VIC	Dandenong Ranges	0%
35	NSW	South Coast NSW	0%
36	NSW	Victoria Snowy Mountains	0%
37	NSW	Victoria Riverland	0%
38	ACT	Australian Capital Territory	0%
39	NSW	South-West NSW	0%
40	NSW	Illawarra	0%
41	NSW	Sydney South	0%
42	NSW	Sydney West	0%
43	NSW	Sydney North	0%
44	NSW	Central Coast NSW	0%
45	NSW	Blue Mountains	0%
46	NSW	Newcastle	0%
47	NSW	Northern Slopes	3%
48	NSW	Mid-North coast	0%
49	NSW	Far North coast	17%

B Risk Frontiers – Literature Review of Historical Tropical Cyclones that Generated Insured Losses

See attached

Literature Review of Historical Tropical Cyclones that Generated Insured Losses



Report Prepared for the Australian Reinsurance Pool Corporation

January 2022

RISK FRONTIERS

Risk Frontiers Disclaimer

This report incorporates the use of data and mathematical and empirical models developed using and including third party data and models. Any and all data, results and other information contained within this report ("Results") are subject to certain inherent limitations including potential errors in the models/ data, shortcomings in the experiment designs, the conjectural quality of the forcing scenarios used to drive the models and statistical uncertainty of model results. While this report has been prepared in good faith, the Results are inherently uncertain (particularly with respect to forward looking matters) and it is not possible within the context and scope of this report to verify the accuracy and completeness of the Results. Accordingly, this report is provided on an "as is" basis. To the maximum extent permitted by law, Risk Frontiers excludes all express or implied representations or warranties related to this report, including, but not limited to, warranties of accuracy, completeness, reliability, merchantability and fitness for a particular purpose. The reliance that the user places on this report, and the Results, is a matter for its own judgment.

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Overview

On 4 May 2021, the Government announced its intention to establish a reinsurance pool for tropical cyclones and related flood damage, to commence from 1 July 2022 and be backed by a $10 billion Government guarantee. The pool would cover residential, strata and small business property insurance policies in Northern Australia.

Tropical cyclones can cause damage through wind and water ingress, storm surge and rainfall-induced flooding. The heavy rainfall associated with a tropical cyclone can persist as it moves inland and decays and well after any landfall. This means that riverine flooding due to a decaying tropical cyclone can occur a significant distance from the tropical coast.

A common approach to modelling the effects of a tropical cyclone is to model damages from wind and water ingress either on their own or together with storm surge. However, the rainfall-induced riverine flooding component of a tropical cyclone is often dealt with in a separate flood model that includes flooding from all sources including tropical cyclones. While this approach reflects the full riverine flood risk profile, it presents a challenge in apportioning the tropical cyclone contribution.

This analysis provides a literature review of historical tropical cyclones that generated insured losses which include riverine flooding from such events. Information is sourced from the Insurance Council of Australia (ICA) Disaster List, Risk Frontiers' in-house database of building damage and fatalities – PerilAUS and Bureau of Meteorology (BoM) reports, amongst other sources. Breakdowns are provided on what proportion of riverine flood damage is attributable to tropical cyclone and covered by the cyclone reinsurance pool, consistent with the pool's definition of tropical cyclone-related flood.

Methodology

Two databases have been created which include flooding events from tropical cyclones that meet the Australian Reinsurance Pool Corporation (ARPC) definition. The first database includes events since 1966, the earliest year of records in the ICA Disaster List. The second database includes events pre-1966, where there is less information available (including event loss amounts).

The available sources that have been used which include historical flooding events from tropical cyclones that generated insured losses include:

- ICA Disaster List
- PerilAUS (Risk Frontiers' in-house database of building damage and fatalities)
- BoM reports
- Various news media reports

The ICA Disaster List[1] is a database of catastrophes that have resulted, on the most part, in significant insured losses. This includes natural disasters through to the COVID-19 pandemic. For this review all the tropical cyclone, flooding and storm events were considered. The earliest event identified was Tropical Cyclone (TC) Elsie in 1967.

Risk Frontiers' PerilAUS[2] database was used to provide additional information for each event. PerilAUS is a database of impacts and consequences of natural hazards in Australia. For over three decades, Risk Frontiers' staff have collected data from a wide variety of newspaper and official sources, focusing on natural hazard incidence, human health and built environment impacts, insurance losses, event analyses, damage indices and risk assessments. PerilAUS holds records on natural hazard impacts in Australia from European settlement (1788), but with good confidence from 1900.

Official reports from the BoM[3], along with other online resources (Wikipedia, Hardenup[4], news articles, blogs, social media, and other reports), were used to complement information from PerilAUS.

Post-1966 Database

The events identified from the ICA Disaster List formed the basis of this database. Additional data was included using the other resources. These were also used to determine whether each TC event produced related flooding losses. The locations affected by flooding were identified and the river catchments that eventually flooded have been recorded. If no flooding was found to occur the event was not included.

The modelling component was used to determine the start and end dates for each event where the Treasury event definition is met. This event duration was then compared to that defined by the ICA, to determine if events met the 48 hr and 72 hr clauses. There were 43 events identified, of which 3 were listed as flood catastrophes and 1 a severe storm by the ICA. It should be noted that the event durations listed by the ICA are not the dates of when flooding occurred, rather

[1] https://insurancecouncil.com.au/industry-members/data-hub/
[2] https://riskfrontiers.com/services/data-solutions-and-other-risks/perilaus/
[3] http://www.bom.gov.au/cyclone/tropical-cyclone-knowledge-centre/history/past-tropical-cyclones/
[4] https://hardenup.org/

they are the dates the claims for each event began to occur, which may be wind or storm damage with the possibility of flooding occurring at a later date. Hence it is possible that flooding occurred outside the event window defined by the Treasury but is unable to be determined.

The fields provided in the database include a classification on the degree of flooding compared to wind damage and other sources, the ICA event names (and cyclone event), the start and end dates (from the ICA, BoM and Treasury definition), loss amounts, the impacted areas, the cyclone tracks, and the event description from PerilAUS.

Each event was assigned a classification (1-5) which is the degree of flood loss in relation to the total loss. The classifications are outlined in Table 1. These were assigned through different techniques depending on the data available for each event. The methods include:

- PerilAUS damage records: a breakdown, where available, of building damage due to flood and other sources.
- Insured loss repartition: The loss due to a particular hazard is explicitly documented, or the flood damage was clearly spatially separated from other damage.
- Expert judgement: The hazard description was used to estimate the damage split.

In most cases expert judgement was used, and this was usually extremely qualitative and heavily biased upon the scope of the available reports. For example, reports aimed at insurers typically focus on damage to buildings, reports for emergency services often describe damage to infrastructure as well as roads and rail disruptions, and reports assessing the damage to the natural environment typically focus on locations which have sustained severe wind or flood but are uninhabited (as is often the case in far north Queensland and large parts of the Northern Territory and Western Australia). Data was sourced from a range of online media sources to gain insight into each event to assign the most accurate classification (percentage of flood loss). These classifications were then used to assign flooding loss amounts.

The ICA normalised loss values are included in the database. These are loss amounts that Risk Frontiers have normalised to 2017/18 societal conditions[5]. Loss normalisation is a process to estimate the impacts of past events on present society and involves adjusting for a variety of factors such as changes in building numbers, values and building codes. The flood classification was then used to assign the approximate amount of loss due to flooding.

Table 1: Flood Contribution Classification.

Class	Flood Contribution to Loss
1	0-25%
2	25-50%
3	50-75%
4	75-100%
5	100%

Pre-1966 Database

[5] McAneney, J, et al. "Normalised insurance losses from Australian natural disasters: 1966–2017." Environmental Hazards 18.5 (2019): 414-433.

To identify relevant events preceding those recorded in the ICA Disaster List, all flooding events in PerilAUS which included the word 'Cyclone' in the event description were considered. Events were filtered out if there was no building damage recorded in PerilAUS and 10 events remained after filtering. We note that it is possible that some events with no building damage did cause damage but it was either not reported or identified.

Event duration was very difficult to obtain for pre-1966 events. There was relatively less information available for these in the literature with most of the relevant information soured from PerilAUS. A further complication was that the formal naming of tropical cyclones in the Australian region only began in 1964 so it was not as easy to identify events. Hence, this database should be viewed as a list of historical events that could have potentially met the ARPC definition but could not be confirmed.

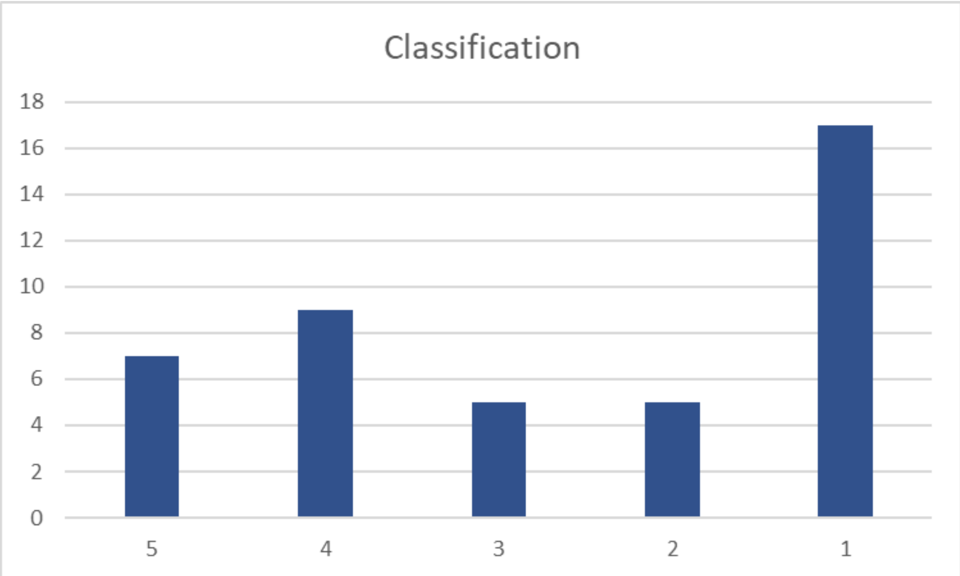
As with the post-1966 database, additional information was included where available. A flood classification of 5 was assigned to all events, as they are only considered flooding events. There are no normalised loss values available for these events, and most don't include an estimated loss in the description. There are some events however that list an event loss in pounds.

Analysis

A list of the historical events meeting the Treasury definition is supplied in an accompanying document (ARPC_TC_FL_Analysis.xlsx).

Figure 1 shows the number of events for each flood classification. The average annual loss (AAL) attributed to flooding for the 44 events identified within the 1966/67 to 2020/21 seasons was $172.8 million. Sixteen of these are class 4 or 5, which are events where the majority of loss was caused by flooding, and together they contribute $130.9 million to the total AAL. There are also 17 class 1 events that have minimal flooding relative to other sources of damage.

Figure 1: Events by Flood Classification.



The rankings of all the tropical cyclones that caused flood losses are presented in Figures 2 & 3. The highest total event loss since the 1966/67 season was from TC Dinah (Figure 2) and the highest flood loss was from TC Elaine (Figure 3). TC Dinah produced some flooding and was assigned the lowest class as the majority of loss came from wind and storm surge. With this classification TC Dinah still ranks as the 5th most costly flooding event, however this may still be an overestimation as class 1 assigns 12.5% of the loss to flooding. TC Elaine was a Category 1 tropical cyclone in the Coral Sea and although it did not make landfall, the rainfall resulted in the highest flood on record in the Herbert River and produced flooding along Brisbane Creeks and Logan River.

In terms of pure flooding events, TCs Madge and Oswald stand out. TC Madge resulted in widespread flooding across Qld and NT and Oswald, a relatively weak tropical cyclone, resulted in torrential rain in Qld which saw flooding along the east coast.

Figure 2: Tropical Cyclone Event Losses with a Flood Contribution (2017/18 normalised values).

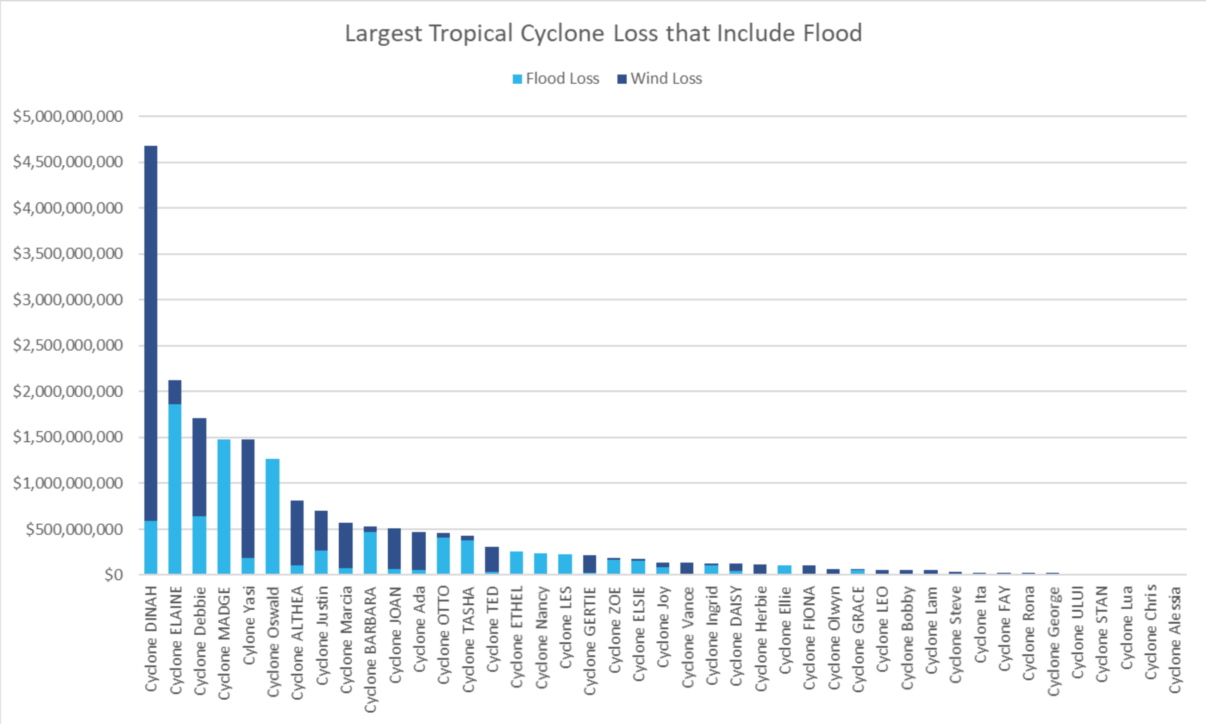
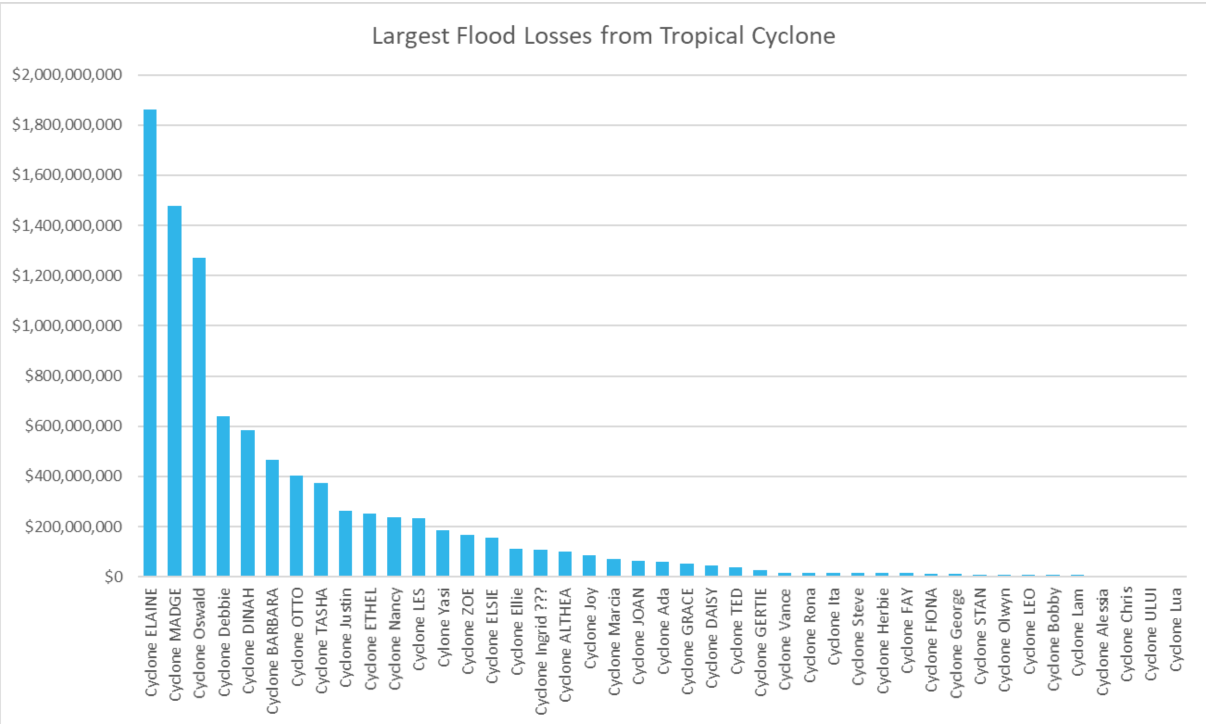


Figure 3: Flood Losses from Topical Cyclones (2017/18 normalised values).



TC Grace is an example where there is uncertainty as to whether it would meet the proposed Treasury event definition. TC Grace had peak gusts of 54 knots (100 km/h), however, it only maintained this intensity for approximately 6 hrs and it weakened before even reaching within 150 km of the Australian coastline. Grace produced extreme rainfall and caused widespread flooding within 48 hrs of the windspeed criteria.

TC Jasmine is another example of an event that may be difficult to classify as it produced rainfall/flooding before meeting the Treasury definition. Early in its existence Jasmine produced numerous rain showers over far north Qld and heavy rainfalls over southern parts of Qld. Its estimated insured loss is $3.6 million. Similar events which cause heavy rainfall before meeting the Treasury event definition could prove difficult to classify.

Figure 4 shows the normalised flood losses by season and includes a 5-yr rolling average. Figure 5 shows the breakdown by region with the eastern side of Australia experiencing the most loss from flooding as well as the most events. The western side experiences very low losses compared to the number of events and this is most likely due to the northern parts of WA being less populated with relatively few and smaller settlements.

Figure 4: Flood Losses from Topical Cyclones by Season.

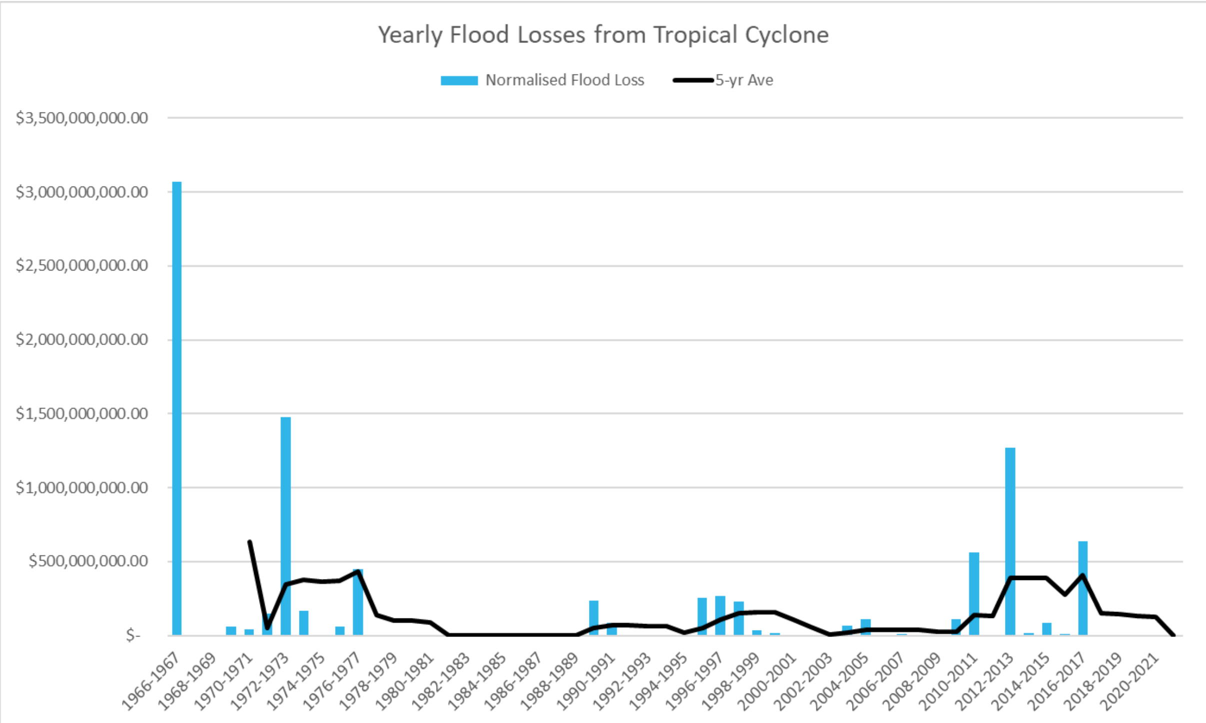
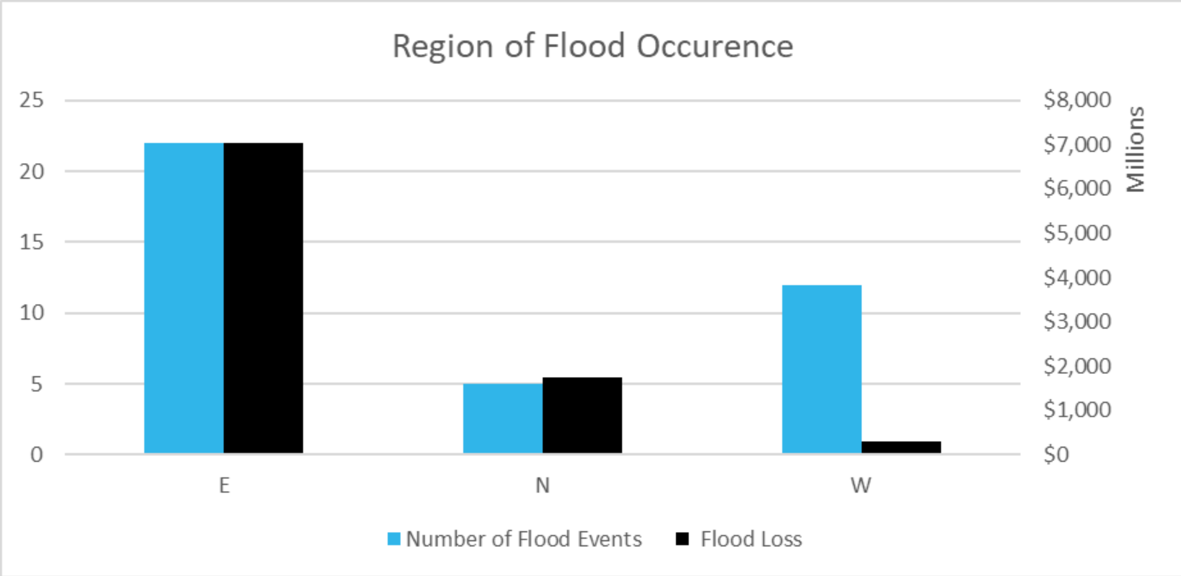


Figure 5: Events by Region.



Summary

Risk Frontiers has analysed historical catastrophe events that included flooding caused by tropical cyclones. Since the beginning of records in the Insurance Council of Australia Disaster List (1966/67 season) 44 flooding events have been identified to meet the Treasury definition, 16 of which where the majority of the loss was caused by flooding. The average annual loss attributed to flooding over this period is $172.8 million ($130.9 million for major flood events), with the majority of these events, and loss, occurring on the eastern side of Australia. The costliest flooding event was caused by Tropical Cyclone Elaine, a category 1 cyclone that did not make landfall but caused record rainfall in the Herbert River.

C Risk Frontiers flood related to Tropical Cyclone study

See attached

Flood related to Tropical Cyclone

Report prepared for the Australian Reinsurance Pool Corporation

January 2022

RISK FRONTIERS™

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Overview

On 4 May 2021, the Government announced its intention to establish a reinsurance pool for cyclones and related flood damage, to commence from 1 July 2022 and be backed by a $10 billion Government guarantee. The pool would cover residential, strata and small business property insurance policies in Northern Australia.

Tropical cyclones can cause damage through wind and water ingress, storm surge and rainfall-induced flooding. The heavy rainfall associated with a tropical cyclone can persist as it moves inland and decays and well after any landfall. This means that riverine flooding due to a decaying tropical cyclone can occur a significant distance from the tropical coast.

A common approach to modelling the effects of a tropical cyclone is to model damages from wind and water ingress either on their own or together with storm surge. However, the rainfall-induced riverine flooding component of a tropical cyclone is often dealt with in a separate flood model that includes flooding from all sources including tropical cyclones. While this approach reflects the full riverine flood risk profile, it presents a challenge in apportioning the tropical cyclone contribution.

In this project we estimate the proportion, by river basin and for a range of return periods, of discharge events (a proxy of flooding) that would generate losses covered by the cyclone reinsurance pool. Riverine floods can occur with a significant delay to a tropical cyclone passing in the proximity of a basin. The Treasury definition of tropical cyclone-related flooding is therefore critical to determine which events, and to what extent, would be covered by the pool. Here, we adopted the definition provided by the current draft legislation, i.e. 48 hours after the earliest time (the downgrade time) when the maximum mean wind speed near the centre of the system falls below 34 knots and remains below 34 knots for at least 6 hours and without re-intensifying within 24 hours. We also consider an extended 72 hours.

The project will assist with setting the riverine flood premium rates for the cyclone reinsurance pool and assist insurers in their assessment of their own riverine flood pricing, to the extent that it helps them to better understand the costs that will be taken over by the pool.

Modelling

Basins

The Australian Hydrological Geospatial Fabric (Geofabric)[1] is provided by the Bureau of Meteorology (BoM) and is a specialised Geographic Information System (GIS). It registers the spatial relationships between important hydrological features such as rivers, water

[1] Australian Hydrological Geospatial Fabric (Geofabric) Product Guide 2015, http://www.bom.gov.au/water/geofabric/documents/v3_0/ahgf_productguide_V3_0_release.pdf

bodies, aquifers, and monitoring points across Australia. We have used the latest available version of Geofabric, v.3.2.1, in this work.

In particular, we used the NCBLevel2DrainageBasinGroup basins boundaries as shown in Figure 1, which represent basin units approximating the Australian Water Resources Management Committee (WRMC) river basins as described in GA (1997). The NCBLevel2DrainageBasinGroup includes 191 distinct basins but we only consider the 134 basins falling within the tropical cyclone-prone areas. Of these, 6 did not produce results because of the small number of historical tropical cyclones intersecting with the basins and either not meeting the Treasury definition of an event or not being matched with a peak discharge event.

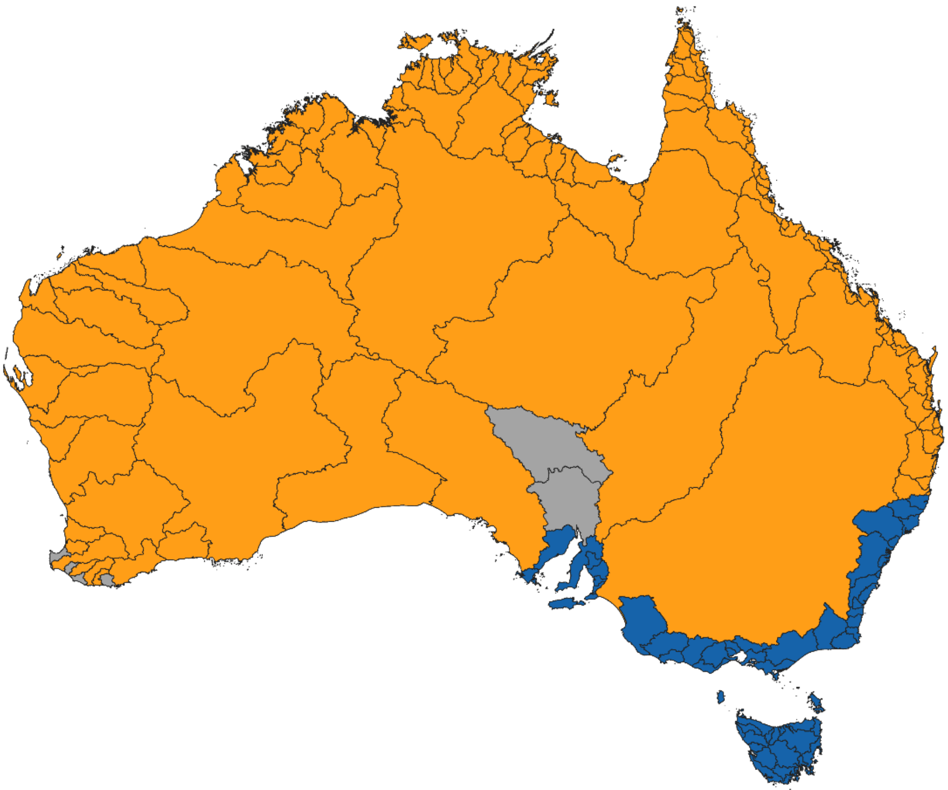

Figure 1: Australian basins: orange – modelled basins; grey – modelled basins without results, and Blue – non-modelled basins.

This analysis could be extended in a future project by using more detailed Hydrological Reporting Basins in Geofabric (~7 million base level basins boundaries derived from the 1 second Digital Elevation Model) which also contain connectivity information used to accumulate flows through a basin including contracted nodes, contracted basins and node-link network.

Tracks Analysis

The best track for each tropical cyclone event in our analysis (1911-2021) was obtained from the BoM's historical tropical cyclone catalogue[2].

[2] Tropical cyclone databases: http://www.bom.gov.au/cyclone/tropical-cyclone-knowledge-centre/databases/

For each event we estimate the time the event started, ended, and when relevant, re-intensified according to the Treasury definition. We also extract the time of landfall(s), identified as the crossing of a smooth 50 km buffered boundary of Australia, and the time intervals during which the track was within 200 km of the coast and hence have the potential to be the cause of heavy rain.

BoM track data is provided at discrete time steps. In recent times these are typically 6-hourly, but they can be also given at shorter intervals, usually around the time of landfall, or longer intervals when the track is far from land. Older track data tends to have more unevenly spaced records and at longer intervals.

The varying time intervals between track data points results in varying uncertainty around the time of start, end, and re-intensification of a tropical cyclone event according to the Treasury definition. Figure 2 shows how the typical time between time steps varies in the BoM track database. The orange and blue lines show a 10-year running average and median value respectively, of the time between consecutive time steps. The shaded areas show the distribution in 5% intervals.

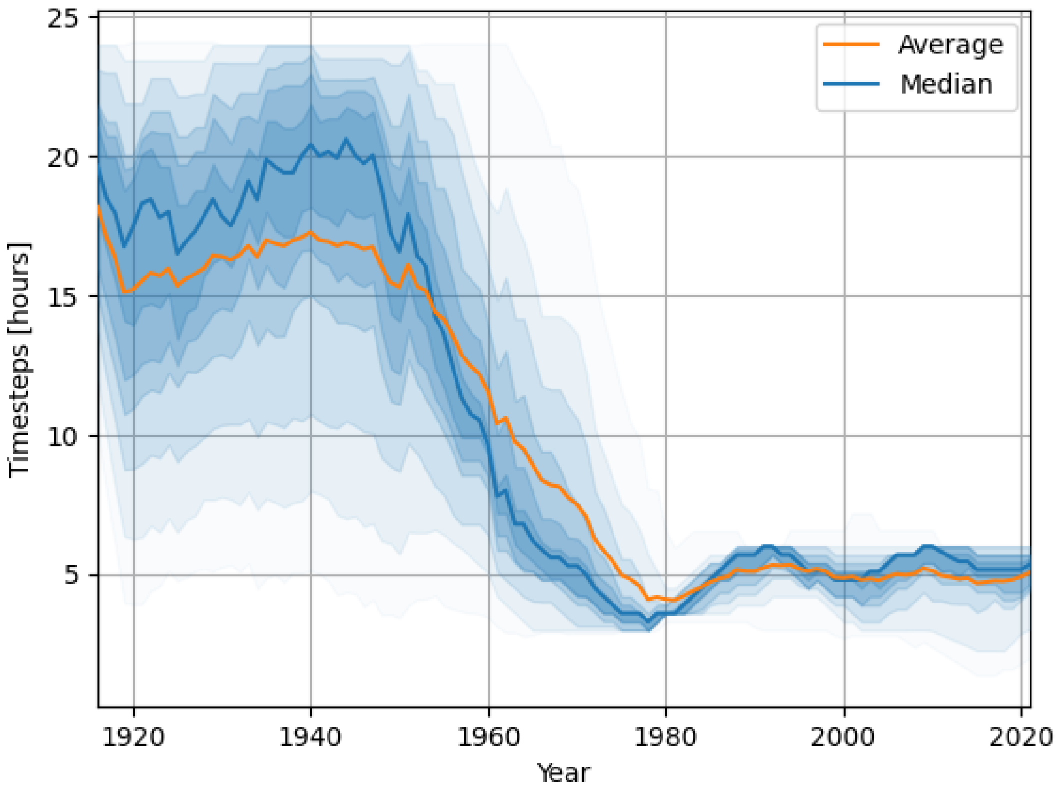

Figure 2: Time in hours between consecutive timesteps in the BoM track database.

The quality of information provided in the historical record also varies significantly through time and Figure 3 summarises the information available in the BoM track database. The figure shows the total number of events in the bottom panel and the ratio of individual records that have information about a particular variable (Cyclone Type, Maximum Wind Speed and Central Pressure). The plots are a 10-years running averages while the shading shows the 10-90% interval.

The figure shows how, before the advent of satellite imaging, i.e. for records before 1972, there is no available information on the Maximum Wind Speed. Consequently, there is also no available information on the BoM Cyclone Type.

The Cyclone Type field is also not provided by BoM for the tracks that are still classified as "Draft" in the database. The sharply decreasing blue curve in Figure 3 clearly shows that the record is not yet finalised for a relatively large number of tracks in recent years.

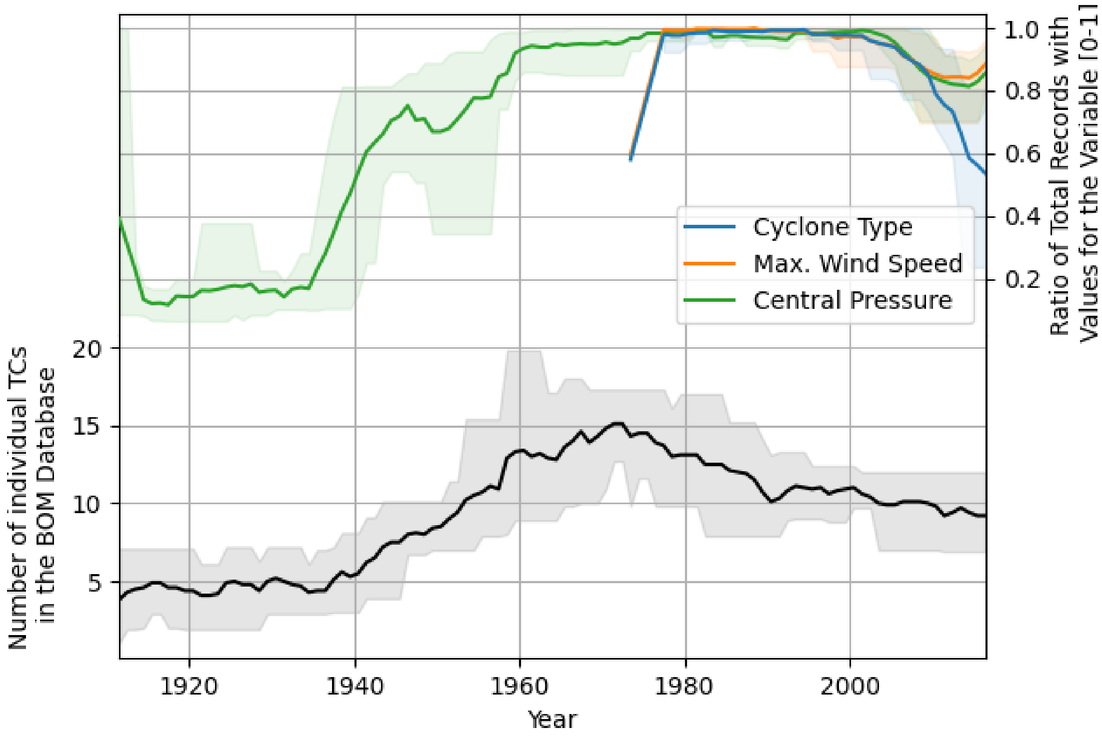

Figure 3: Data availability in the BoM track database.

In our analysis we considered all events since 1911 that have a maximum lifetime intensity of at least Category 1 and come within 200km of the Australian coastline. The tropical cyclone category at each time step is estimated from the best information available in the BoM database, In order of preference:

1. Cyclone Type as assigned by BoM: with "34-63 knots (17-32m/s) more than two quadrants" being the minimum requirement for being a cyclone according to the Treasury definition.
2. Maximum Wind Speed: ≥17.5 m/s being the minimum requirement for being a cyclone according to the Treasury definition.
3. Central Pressure: ≤995 hPa being the minimum requirement for being a cyclone according to the Treasury definition.
4. If no information at all is provided, we assume that the whole track is cyclonic in nature. This typically only happens for the oldest tracks that tends to only include severe events.

A tropical cyclone event is split into separate sub-events according to the Treasury definition if the tropical cyclone event decays to an intensity lower than the minimum requirement listed above and then re-intensifies after longer than 24 hours. Events that re-intensify within 24 hours are considered as a unique event according to the Treasury definition.

Basins Discharge Analysis

While it is not a certainty that peak river flows result in flooding, there is a strong causal relationship between flood events and elevated river discharge. Here we use peak river discharges as a proxy for flooding. The extent to which a river floods is also related to flood mitigation measures (levees, weirs etc.), the in-channel capacity to store floodwater (channel cross-section) and the role of storm surge intrusion up-river and overland (pluvial) flooding. These have not been explicitly investigated as part of this project.

Daily gridded rainfall and runoff data from the Australian Water Availability Project (AWAP) and the Australian Landscape Water Balance project (AWRA-L)[3] were used to derive a 111-year storm discharge history (1911-2021) for 134 river basins in Australia. While there are 191 river basins in total in Australia, we model only the ones falling within the tropical cyclone-prone areas.

AWAP and AWRA-L provide, amongst other variables, daily (the accumulation in the 24-hr to 9 am AEST the current day) rainfall and runoff maps across Australia on a 0.05° grid (5-6 km^2) from 1911 (1900 for AWAP) to present.

AWAP uses all available rain station data across Australia that is held in the Australian Data Archive for Meteorology (ADAM). The quality at any location is thus dependent on the density of observations. AWAP does not use a climate model and is derived only from observations.

AWRA-L is a daily 0.05° grid-based, distributed water balance model, conceptualised as a small unimpaired basin. It simulates the flow of water through the landscape from the rainfall entering the grid cell, from AWAP, through the vegetation and soil moisture stores and then out of the grid cell through evapotranspiration, runoff, or deep drainage to the groundwater.

Each spatial unit (grid cell) in AWRA-L is divided into two hydrological response units (HRU) representing deep rooted vegetation (trees) and shallow rooted vegetation (grass). Hydrological processes are modelled separately for each HRU, then the resulting fluxes or stores are combined to give cell outputs. Hydrologically, these two HRUs differ in their aerodynamic control of evaporation and their interception capacities but the main difference is in their degree of access to different soil layers. The AWRA-L model has three soil layers (upper: 0–10 cm, lower: 10–100 cm, and deep: 1–6 m). The shallow rooted

[3] The Australian Landscape Water Balance model (AWRA-L v6): http://www.bom.gov.au/water/landscape/assets/static/publications/AWRALv6_Model_Description_Report.pdf

vegetation has access to subsurface soil moisture in the upper and lower soil stores only, while the deep-rooted vegetation also has access to moisture in the deep store.

A zonal mean daily runoff value was calculated from the AWRA-L data for the period 1911-2021. While this provides a good representation of rainfall runoff over small basins, it may not replicate localised rainfalls in large basins well. Rainfall events were identified within each basin's 111-yr rainfall/runoff timeseries, using a simple Peaks Over Threshold (PoT) criterion. An 'event' was identified as the consecutive days with a runoff value larger than the 90th percentile of each basin.

A Synthetic Unit Hydrograph (SUH), using the Soil Conservation Service method[4] was derived for the most downstream location in each basin (outlet point), to estimate the river's discharge response to rain falling on the basin upstream of it. A SUH describes the direct runoff response of a river to one unit of constant intensity uniform excess rainfall (runoff) occurring over the basin[5]. It is a useful concept in flood modelling because it can be used to predict the discharge response of a river to a rainfall event of any magnitude or duration. For locations where no direct river measurements exist, a SUH is required. A SUH shape is determined by the mean characteristics of each basin, such as slope and land use, and the basins' area and hydraulic length.

Each daily SUH is scaled by the actual volume of the excess rainfall (runoff) pulse, and then every scaled SUH is then lagged and summed over the duration of the storm to obtain a direct runoff hydrograph (DRH). In doing this, the daily runoff values were uniformly down-sampled to 1-hrly intervals to properly model the timing and peak of the storm discharge. This step does not add new information, but it is important in reducing aliasing in the superposition of excess rain from subsequent days, especially for those basins that have a modelled lag time of accumulation significantly shorter than a day.

In this way, a river storm hydrograph could be modelled for each rainfall event, incorporating the basin physical properties (area, river length, slope, and land use) (Figure 4). Hydrographs from individual rain events close enough in time to produce overlapping hydrographs are grouped into the same discharge event with the overlapping hydrograph values superimposed. In the absence of detailed data, the ambient flow of a river independent of heavy rainfall was assumed to be constant for each basin over the 111-yr period.

It is important to note that this method is likely to underestimate the rainfall intensity (and consequentially peak river flow conditions) during historical tropical cyclones because it is derived originally from daily rainfall totals. While various reanalysis products provide sub-daily rainfall hindcasts, previous comparisons against observations suggest they are of a lower quality than AWAP. Reanalysis data is modelled, while AWAP is a re-interpolation of historical observations.

The impact of storm surge and overland flow on river levels is not accounted for here.

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[4] SCS. Soil Conservation Service. "Design of hydrograph". US Department of Agriculture. Washington, DC 2002.

[5] L. Sherman, "Stream Flow from Rainfall by the Unit Graph Method," Engineering News Record, No. 108, 1932, pp. 501-505.

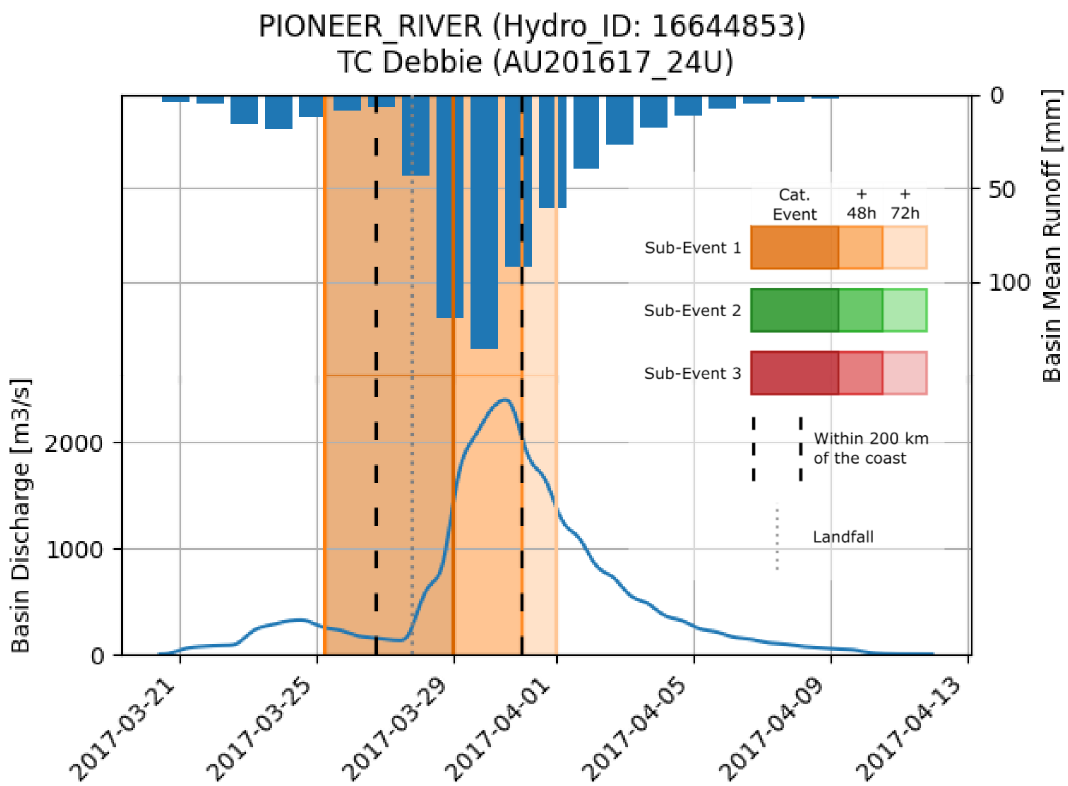

Figure 4: Example of a basin discharge hydrograph: Pioneer River basin during Tropical Cyclone Debbie. The bars on the top half represent the daily excess rain (runoff) measurements from AWRA-L. The plot in the bottom half represents the modelled Basin Discharge hydrograph for the basin. The vertical-coloured bands and dashed or dotted lines show the estimated significant times of the tropical cyclone, as explained in the legend. As TC Debbie has been modelled as a single event for the pool's proposes (i.e. no decay and re-intensification) only Sub-Event 1 bands are shown in the plot.

Attribution of Flood Events to Tropical Cyclones

For each event, catchments within a 150-km radius of the track were selected (Figure 5). This distance is large enough to identify the catchments potentially affected by tropical cyclone related rainfall as it is larger than 80% of the recorded over-land gale-force wind radii in the BOM cyclone database. At the same time it constrains the catchments selection to a distance that is unlikely to include rainfall originating from separate whether systems. The river discharge was selected from the 111-yr timeseries (described above) within a 14-day window beginning at the time the event crossed the 200 km buffer boundary. This time window is used to determine river discharges that may have been attributable to the tropical cyclone event.

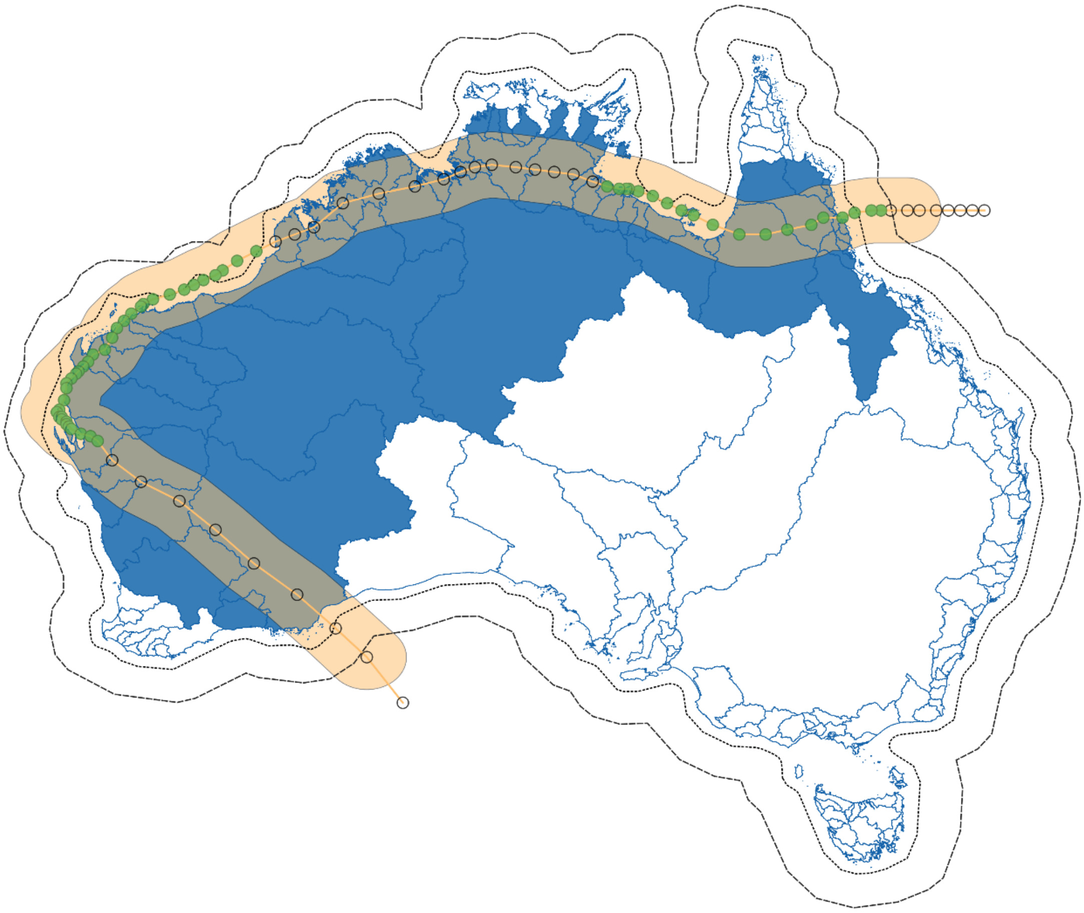

Figure 5: Tropical Cyclone Steve. The orange line represents the cyclone track, the orange shade represents the 150 km radius buffer to the track used to identify the basins affected by the cyclone. The buffer is only applied to the sections of the track within 200 km of the coast (the outmost dashed contour of Australia). The circles indicate the individual time steps in the track's data. Green circles indicate the cyclone is an event according to the Treasury definition.

For each tropical cyclone event, the timing and volume rate of the highest basin discharge peak in each affected basin was retained. In some instances, there were more than one discharge peak recorded in a single catchment within the 14-day window; in others, there were no discharge peaks even though the catchment was within the 150-km radius of the tropical cyclone.

We also record the maximum value of each basin discharge event within the window spanning from the estimated beginning of the event to 48 and 72 hours after the end of the event, according to the Treasury definition. In the example shown in Figure 4, the basin discharge of the Pioneer River during Tropical Cyclone Debbie, the peak discharge, the maximum value within the 48 hours window and the maximum value within the 72 hours window are the same as the peak occurs within the 48 hours window.

Some tropical cyclone events did not produce a streamflow response in any of the 134 catchments modelled. We also note that flooding is possible beyond the extent of the track recorded in the BoM catalogue.

Annual Occurrence Exceedance Probability

We extract the time series of annual peak discharge maxima of each basin. We then fit a generalised extreme value distribution (GEV) to the data using the method of linear moment[6] in order to estimate an annual exceedance probability curve for each basin. We can then assign an estimated return period to each of the discharge events.

Figure 6 shows, as an example, the modelled annual exceedance probability curve for the Pioneer River Basin. This is overlayed by a scatter plot of the estimated return period of the basin discharge events. The orange data is all the peaks of discharge events for the basin, in green, the subset of peak discharge events that are estimated to be related to a tropical cyclone, as defined in the previous section, in red and purple the maximum value, of discharge events within the window spanning from the estimated beginning of the event to 48 and 72 hours after the end of the event. Start and end time are as defined by Treasury. The maximum value of discharge and hence return period within the time window that would be covered by the pool is often lower than the peak of the discharge event.

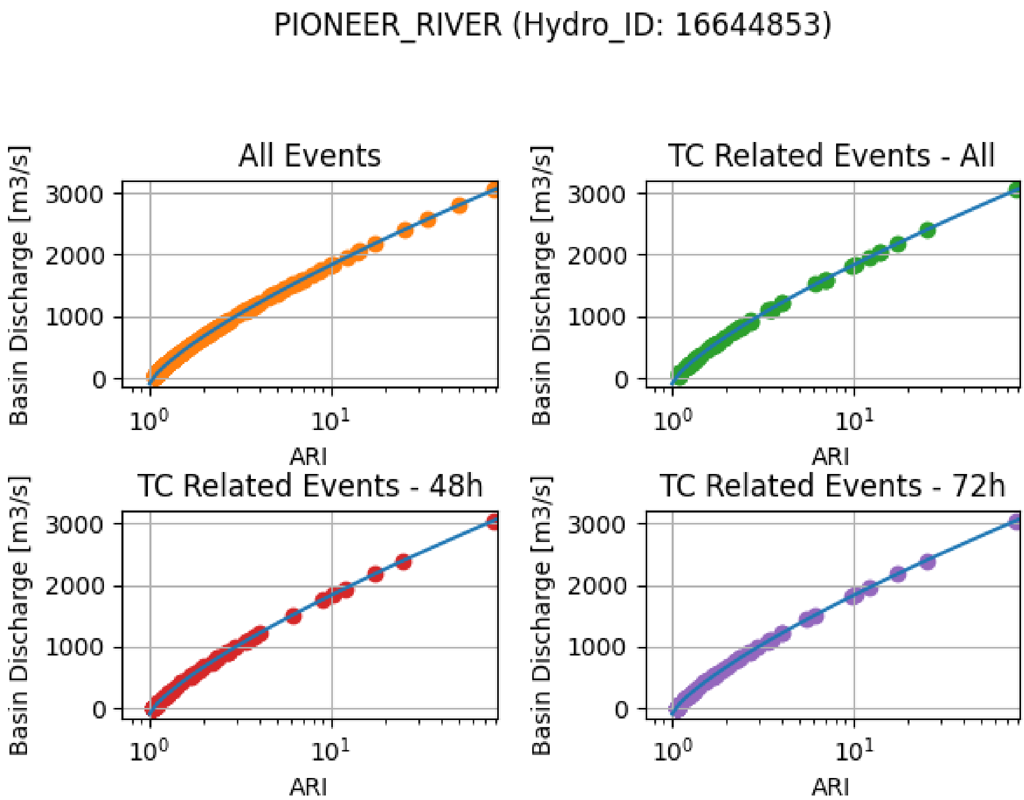

Figure 6: Example of modelled Annual Exceedance Probability curves and estimated return periods of events according to a range of definitions. TC Debbie, shown in Figure 4 is estimated to have produced a river discharge in the Pioneer River corresponding to a return period of just over 25 years.

[6] Hosking, J.R.M and Wallis, J.R. "Regional Frequency Analysis: An Approach Based on L-moments". Cambridge University Press, UK, 1997.

Results

The main result of this work is the estimation of the proportion, by river basin and for a range of return periods, of discharge events (a proxy of flooding) that would generate losses covered by the pool.

Figure 7 shows an example of the results for two neighbouring basins in southern Queensland: The Pine River Basin and the Brisbane Basin. Results are calculated for all the discharge events happening within a 14-day window to capture all the basin discharge events potentially related to the tropical cyclone event, in blue, and within the 48 hours and 72 hours windows as defined by Treasury, in orange and green.

By comparing the results for the two basins it is immediately evident the impact of the size of the basin on the estimated time of discharge. The two basins are next to each other and essentially affected by the same meteorological events. This is confirmed by the similar distribution of the blue and green bars in the two basins. The Brisbane River basin though is much larger than the Pine River basin and floodwater takes longer to accumulate downstream, resulting in not many events producing significant river discharges within the 48 hours window (the orange bars).

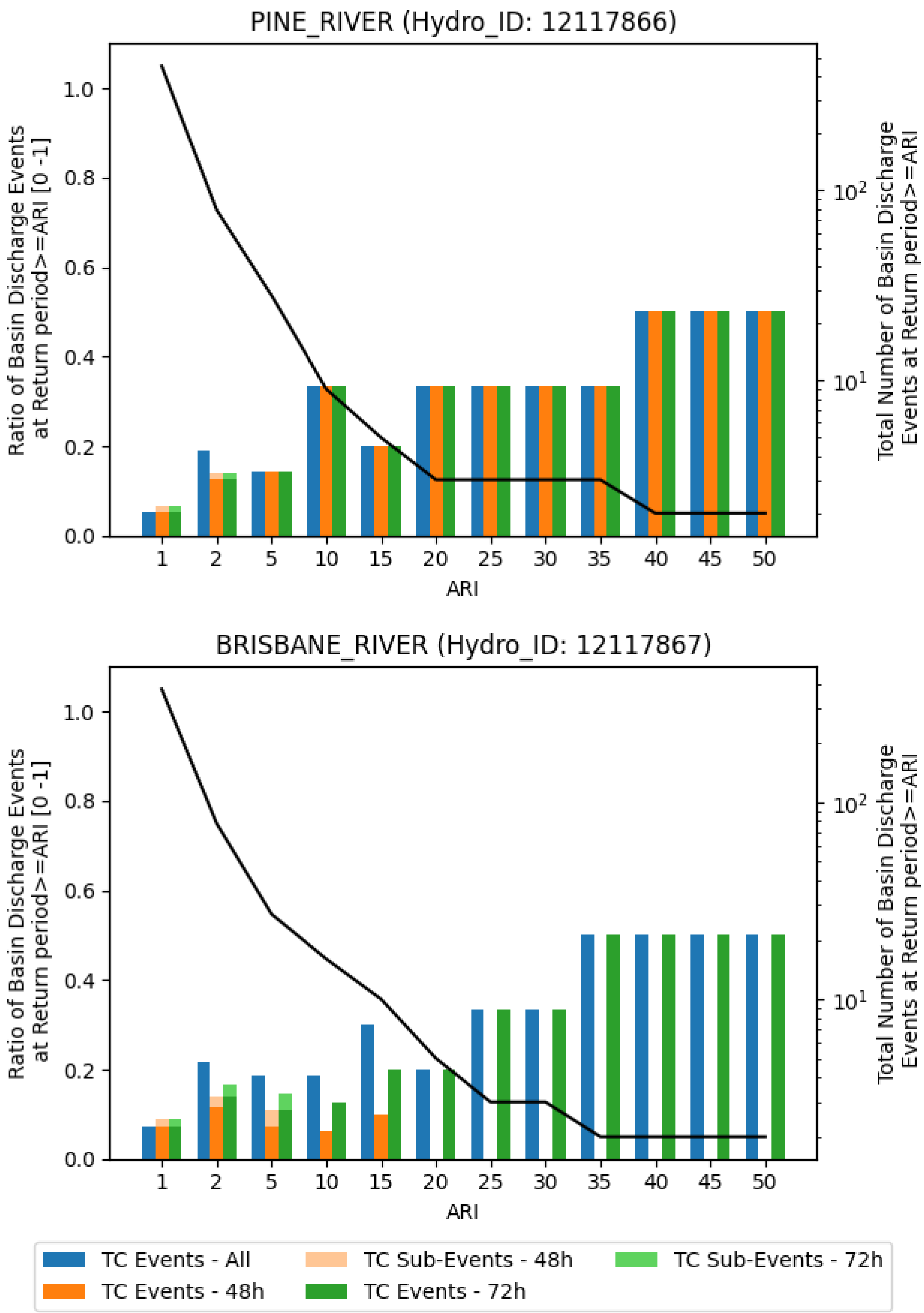

Figure 7: Example of the proportion, for a range of return periods, of discharge events that would generate losses covered by the pool under the 48 (orange) and 72 (green) hours event.

Cresta Weighting Factors

To aggregate results at a Cresta level we also provide a mapping table that includes for each Cresta Zone (revised ICA Zones) the weight to assign to results from the intersecting basins.

The exposure distribution is not uniform within a Cresta Zone nor all addresses within a Cresta are exposed to flood risk. The weight of each basin within a Cresta Zone then, is determined by the ratio of addresses (G-NAF[7] addresses from Q1 2021) at risk. Addresses are considered at risk if they lie within a floodplain as modelled in the Risk Frontiers Flood Exclusion Zones (FEZ) [8] (Figure 8).

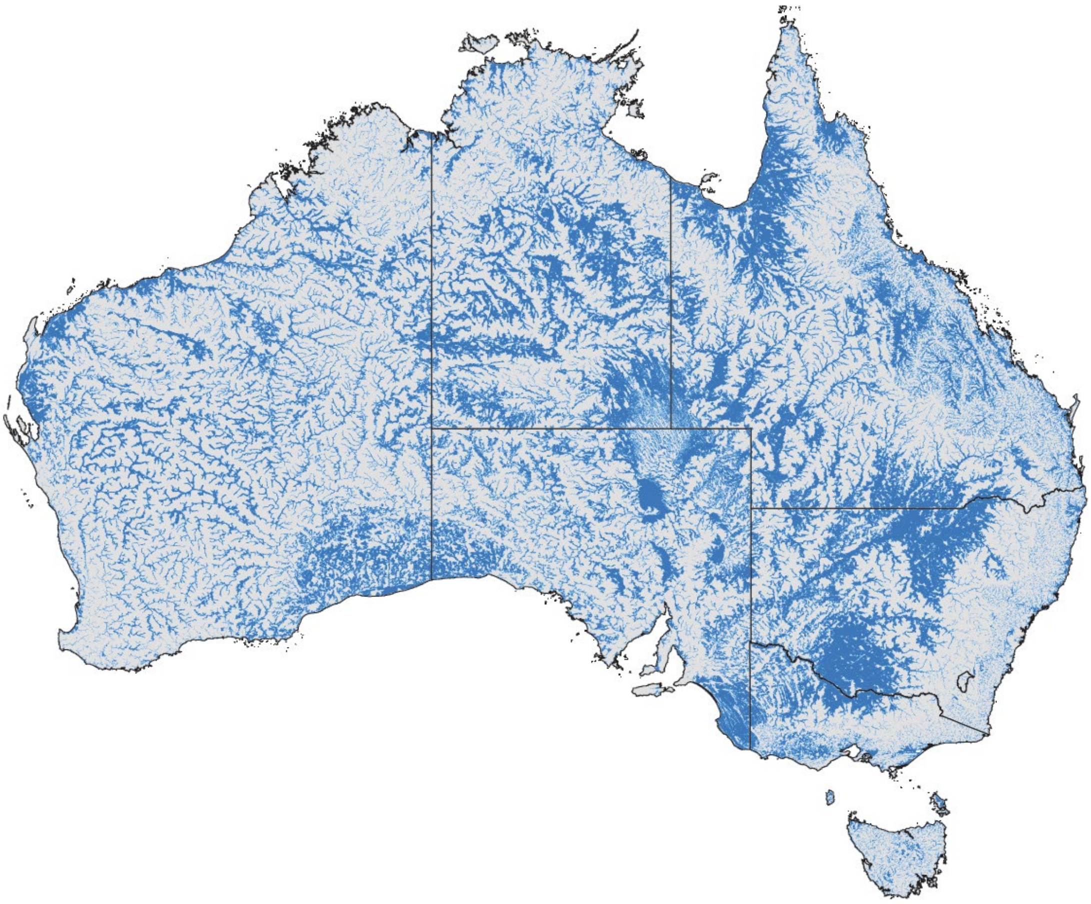

Figure 8: FEZ Version 11.0: Modelled floodplains are in blue.

Results of Interest

For most of the events, like Tropical Cyclone Steve in Figure 5, it is straightforward to isolate individual events, according to the Treasury definition, within a tropical cyclone and attribute basin discharge events to one or another as they are well separated both in space and time.

This is not always the case. Looking for example at Tropical Cyclone Ethel in Figure 9, we can see two individual events, according to the Treasury definition, as in Tropical Cyclone Steve. In this

[7] Geoscape Geocoded National Address File (G-NAF): https://data.gov.au/dataset/ds-dga-19432f89-dc3a-4ef3-b943-5326ef1dbecc/details

[8] https://riskfrontiers.com/services/models/floodaus/

case though the two events affect largely the same basins in Far North Queensland.

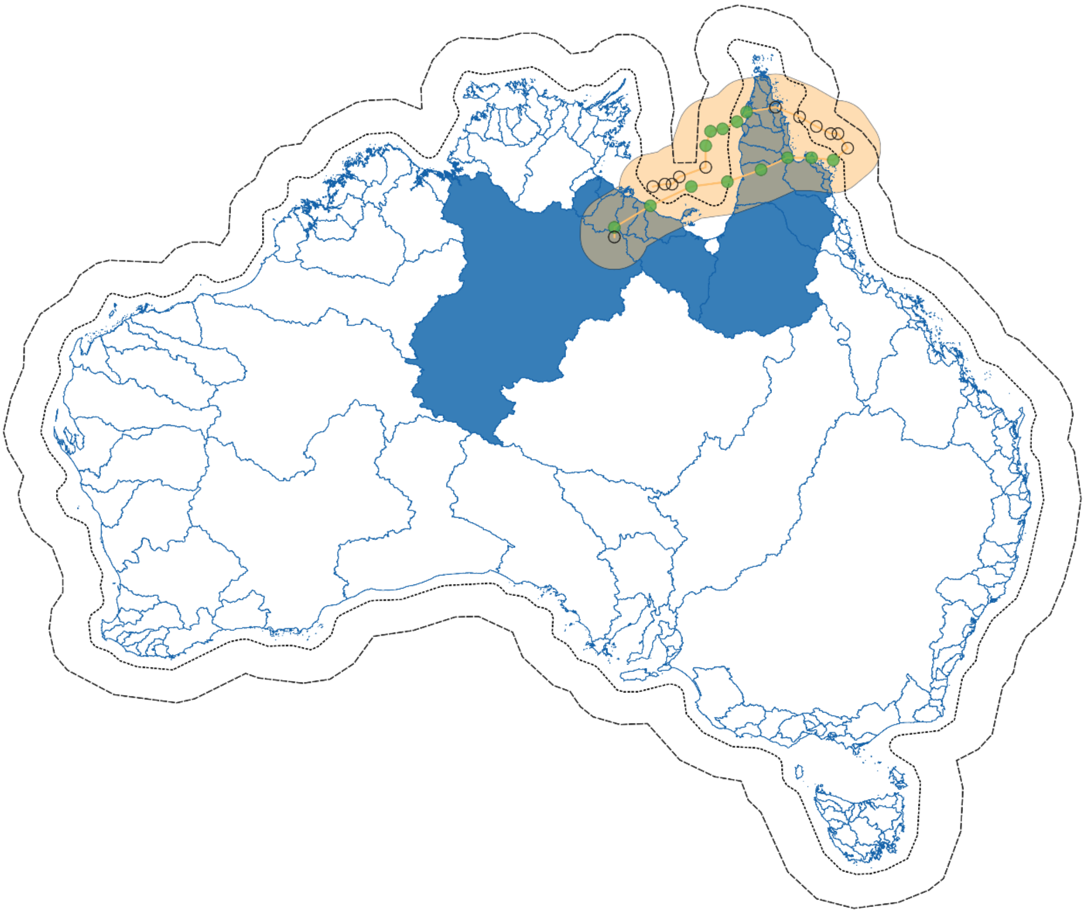

Figure 9: Tropical Cyclone Ethel. The orange line represents the cyclone track, the orange shade represents the 150 km radius buffer to the track used to identify the basins affected by the cyclone. The buffer is only applied to the sections of the track within 200 km of the coast (the outmost dashed contour of Australia). The circles indicate the individual time steps in the track's data. Green circles indicate the cyclone is an event according to the Treasury definition.

The resulting discharge event for these basins cannot be separated into separate events, see for example the hydrograph for the Lockhart River basin in Figure 10.

In the occurrence of similar events the cyclone reinsurance pool would have to solve the problem of apportioning eventual tropical cyclone related flood losses to individual cyclone events resulting in a unique flood event. The same issue would arise from independent tropical cyclones hitting the same regions in short succession or tropical cyclone related rain exacerbating a pre-existing flood event.

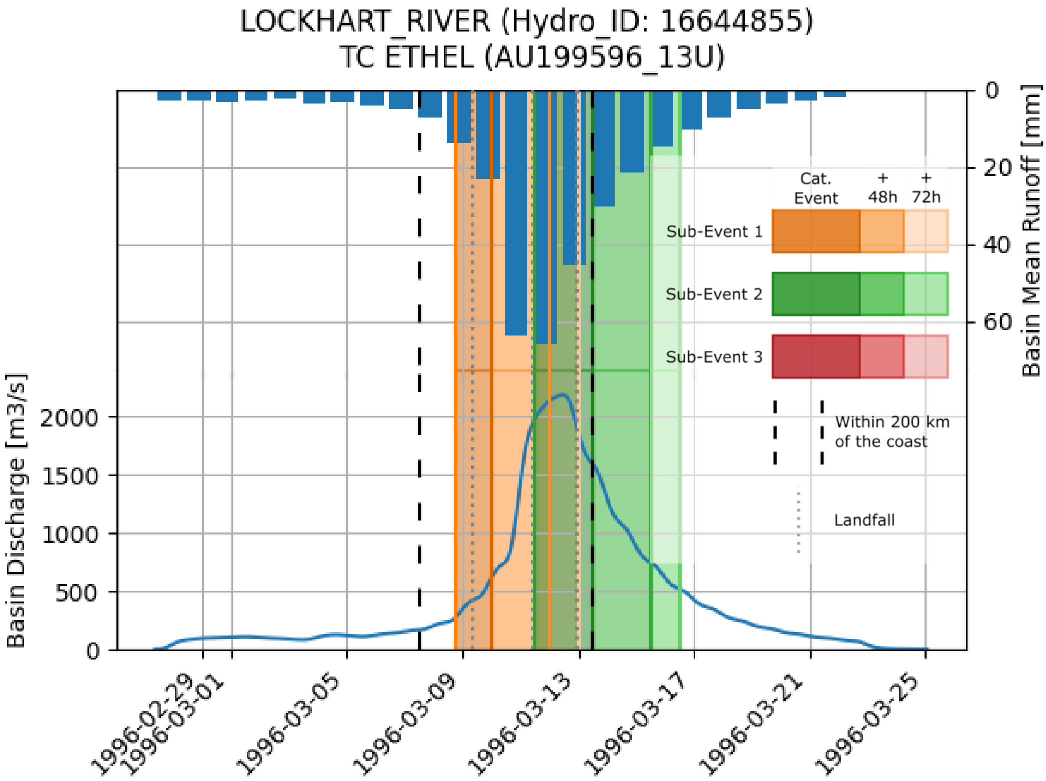

Figure 10: Lockhart River basin during Tropical Cyclone Ethel. The plot in the bottom half represents the modelled Basin Discharge hydrograph for the basin. The vertical-coloured bands and dashed or dotted lines show the estimated significant times of the tropical cyclone, as explained in the legend. As TC Ethel has been modelled as two events for the pool's purpose only Sub-Events 1 and 2 bands are shown in the plot.

finity