Unprecedented? Unlikely.

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Key Points

- Larger floods have occurred prior to gauging records.
- There is multiple evidence of floods larger than contemporary "unprecedented" floods.
- Palaeoflood and palaeoclimate data have real-world applications.
- Understanding palaeofloods can improve waterway and flood management in the context of climate change.

Abstract

The term 'unprecedented' is often used in the media to describe contemporary extreme weather events. The magnitude of these extreme events is often not recorded. However, evidence of extreme floods from the past has been found throughout Australia and elsewhere. Physical evidence from fluvial sedimentary records can provide critical insight into the magnitude and frequency of significant flood events that occurred well before gauging began. Many of these are of greater magnitude than in the records.

Palaeoflood hydrology is the study of floods which occurred prior to written records. A common technique in a palaeoflood study is the use of fluvial sedimentary records in low-energy depositional areas (Baker, 1987). Hydraulic modelling and dating techniques provide information on the magnitude and frequency of the past extreme flood events through the preservation of sediments in the physical environment. In Australia, there has been a significant increase in palaeoflood studies in the last decade with the discipline evolving from academic research to real-world application.

"Unprecedented" floods are generally attributed to climate change. Such floods, and many larger, are not unprecedented. Rather, palaeoflood information can help us conceive and understand the potential for larger floods in the future due to accelerated climate change, and they are certainly useful evidence in guiding waterway and flood management.

Keywords

Unprecedented, Extreme Events, Palaeoflood Hydrology, Climate change induced extreme events.

Introduction

The climate is now changing at a much faster rate, not least caused by anthropogenic activities. There is a clear increase in both frequency and magnitude of extreme weather events. The term "unprecedented" is increasingly used as a narrative to illustrate the magnitude and severity of these extreme weather events. This is not limited to mainstream and social media, but also in scientific reports and publications. As the term suggests, these contemporary extreme events are often not witnessed or recorded by instrumentation or written records. However, this does not mean that such events have not occurred prior to records or that they were not witnessed and observed, particularly by Indigenous people (Goodall, 2008). In fact, evidence of extreme floods from the past have been found throughout Australia and elsewhere. Ongoing research across Australia has revealed extreme periods and/or magnitudes of weather events. For example, the 2000-2007 South East Queensland drought has almost certainly been exceeded in duration numerous times in the last thousand years (Kiem et al., 2020). At the other end of the hydro-spectrum, extreme palaeoflood records have increasingly been identified across Australia. For example, at least one flood with a peak height of over 8.0 m higher than the largest recorded flood on the Nepean River just west of Sydney occurred before written records were kept (Saynor et al., 1993).

The term “unprecedented” can therefore have misleading consequences. “Unprecedented” extreme events can perhaps be perceived as Black Swan events (Taleb, 2007). Traditionally used in the finance sector, but increasingly elsewhere, Black Swan events are consequential occurrences that are unexpected and impossible to predicted. They are often considered outliers because no seemingly known data of such scale exists. Examples of Black Swan events include the rise of the internet, World War 1 and the September 11 attack. The issue here is two-fold. First, it creates a sense of helplessness in that such events are unexpected and unpredictable. Second, there is a misconception that there is really nothing one can do as there is no precedent data available to be better prepared for these events. However, with palaeoclimate data, we now know that the abovementioned issues can be resolved, and we can no longer feign ignorance. With increasing uncertainty and vulnerability to climate change, palaeoclimate data can play an important role in forecasting what may happen in an uncertain future. There are collective efforts on multiple fronts collating palaeoclimate data. For example, Croke et al. (2021) produced the PalaeoWISE (Palaeoclimate Data for Water Industry and Security Planning) (https://palaeoclimate.com.au/) database, an example of a palaeoclimate data source.

The reminder of this paper will focus on floods by providing an overview of palaeoflood reconstruction; showcasing palaeoflood data across Australia that are greater than those recorded by gauges; and identify how palaeoflood records can be used in the realm of waterway and flood management in the context of climate change.

Overview of Palaeoflood Hydrology

Palaeoflood hydrology is the science of reconstructing the magnitude and frequency of past floods, which occurred prior to formal record keeping (Baker et al, 1987). Introduced as a scientific discipline by Kochel and Baker in 1982, this interdisciplinary science has since evolved significantly with advanced development and maturity in techniques and applications. The science involves the use of evidence from nature (river and lake sediments, tree rings, speleothems, etc), with two typical objectives: 1) understanding when the extreme floods happened and 2) quantifying how large they were. These involve the use of dating techniques (such as radiocarbon dating and optically stimulated luminescence dating) and hydraulic modelling, both of which provide information on the magnitude and timing of past extreme flood events. The most common evidence used is sedimentary archives that occur in the natural environment (Figure 1). During a flood event, sediments are transported by floodwaters and subsequently deposited in low-energy depositional areas. In locations where they are well-preserved, they provide a natural record of past floods.

The applications of palaeoflood hydrology have been well described elsewhere and therefore not discussed in detail here (see e.g. Benito and Thorndycraft, 2005; Benito et al., 2023). In Australia, the first palaeoflood study was completed by Baker et al. in 1983. Since then, there have been numerous studies producing multiple palaeoflood records across Australia. The development trajectory of the discipline has gradually shifted from academic research to industry applications. Palaeoflood data is recommended for inclusion in Flood Frequency Analysis (FFA) in the Australia Rainfall and Runoff Guidelines (AR&R) (Ball et al., 2019). Some applications in Australia are summarised in Table 1.

Figure 1. Example of sedimentary sequence of flood deposits. Individual flood units are typically identified as a sequence from basal of coarse to fine sediments with a sharp reversal in grain size to the next overlaying flood unit. (Source: Author. Location: Northern Thailand)

Table 1. Examples of Palaeoflood Hydrology Applications from Australia

Application	Location	Source
Mine Site Rehabilitation/ Mine Closure	East Alligator River, NT	Saynor et al, 2020
Contextualising Extreme Outliers	Callide Creek, Qld	Centre for Catchment and Flood Management, 2017
	Lockyer Creek, Qld	Sandercock, 2012
Improve confidence in estimation of design flood quantiles	Weeli Wooli Creek, WA	Water Technology, 2024
	Nogoa River, Qld	Water Technology, 2023
	Burdekin River, Qld	Jordan et al., 2021
	Burnett River, Qld	Lam and Broit, 2021
Comparing against contemporary extreme events	Nogoa River, Qld	Water Technology, 2023
	Burnett River, Qld	Lam and Broit, 2021
Identifying regional signatures of past extreme events	Central Queensland	Water Technology, 2023
	Callide and Kroombit Basins, Qld	Water Technology, 2021
Relating climatic drivers and extreme floods	Barron River, Qld	Lim et al., 2024
	Multiple locations, Qld	Lam et al., 2017b
Estimating pollutant mass loads from extreme events	Barron River, Qld	Lim et al., 2024

Palaeoflood Records and Gauge Records

Palaeoflood records provide a natural archive of extreme floods in Australia and elsewhere. Table 2 provides a list of collated palaeoflood records in Australia where the palaeoflood record is of a greater magnitude than the gauge's Flood of Record (FoR). The ratio of the specific discharges shows palaeoflood records are over six times greater than the gauge records in some locations. The list in Table 2 does not include other palaeoflood records elsewhere in Australia that have discharge estimates that are close to, or in the same order of magnitude as, the FoR. It is important to note that the discharge associated with the palaeoflood records, at least for those derived from sedimentary archives is conservative and a minimum threshold value. The derivation of the palaeoflood discharge values is associated with the elevation of the sedimentary deposit, which is almost always lower than the peak stage height of the flood event. As such, the actual discharge of the palaeoflood event is likely to be higher and can be as much as 20% (Lam et al., 2017b).

Table 2. Flood of Records (FoR) and palaeoflood discharges in Australia*

State	River	Area above gauging station (km^2)	Q_{FoR} (m^3s^{-1})	Area above Study Site (km^2)	Q_{PALAEO} (m^3s^{-1})	Specific Discharge Q_{SPEC_FoR} (m^3s^{-1} km^2)	Specific Discharge Q_{SPEC_Palaeo} (m^3s^{-1} km^2)	Ratio	Source
NT	Katherine	6390	5168	6390	6300	0.8	1	**1.2**	Baker et al. (1985), Baker & Pickup (1987)
NT	East Alligator	2384	9233	2384	60600	3.9	25.4	**6.6**	Saynor et al. (2020)
NT	Finke	7500	1668	6000	8200	0.2	1.4	**6.1**	Baker et al. (1983), Wohl et al. (1994a)
QLD	Barron River	1779	6440	1841	161,592	3.6	8.8	**2.4**	Lim et al. (2024)
QLD	Nogoa	13880	5868	13800	8900	0.4	0.6	**1.5**	Water Technology (2023)
QLD	Burnett	30670	16668	16100	21000	0.5	1.3	**2.4**	Water Technology (2021)
QLD	Baramba	5553	7594	5556	9,000	1.4	1.6	**1.2**	Lam et al. (2017a, b)
QLD	Emu Creek	915	2036	904.5	3000	2.2	3.3	**1.5**	Lam et al. (2017b)
QLD	Nerang	68	494	79	650	7.3	8.2	**1.1**	Lam et al. (2017b)
QLD	Herbert	5236	15336	5500	17,000	2.9	3.1	**1.1**	Wohl (1992a)
QLD	Burdekin	114700	19196	114700	30000	0.2	0.3	**1.6**	Wohl (1992b)
WA	Fitzroy	46133	25546	35000	30,000	0.6	0.9	**1.5**	Wohl et al. (1994b)
WA	Margaret	7646	8930	7800	20000	1.2	2.6	**2.2**	Wohl et al. (1994b)

*Modified and updated from Lim et al (2024)

Palaeoflood Hydrology in waterway and flood management in the context of Climate Change

Palaeoflood records can be used to improve waterways and flood management. Incorporating palaeoflood and palaeo-hydroclimate information is necessary, to not only improve our estimates of risk in waterway and flood management, but also improve land management, provide inputs to land use planning, transport and infrastructure design, and most importantly protect communities (Allen et al. 2020).

There is increasing research attempting to unravel the complex connections between period of large floods (and droughts) with major climatic drivers, including El Niño Southern Oscillation (ENSO), the Interdecadal Pacific Oscillation (IPO) and the Indian Ocean Dipole (IOD), using paleoclimate data, including palaeoflood records. Improving our understanding of these climatic drivers will be critical in anticipation of periods of increase frequency of extreme events in a future with accelerated climate change.

Climate change increases the uncertainty of future flood projections. To allow for a more flexible adaptation to climate change, the use of palaeoflood records from a wide spectrum of hydroclimatic variability can allow for a more robust and reliable assessment of flood hazards (Bentio et al. 2020). They can also be used to test hydrologic models for climate change projections (Wasson and Lam, 2022).

Using the comparisons in Table 2, one might argue that i) gauge records could be relatively short, ii) extreme events may not have occurred after the gauging commenced, or iii) the gauge did not accurately capture the large events that had occurred due to hardware malfunction or damage to the gauge by large flow events. These are valid arguments and are likely accurate synopsis of issues with most gauges and their records across Australia. However, these are also the very reasons that palaeoflood records can complement, validate and improve gauge records. Palaeoflood science can provide data of extremes not available in the gauge records.

To illustrate, the incorporation of palaeoflood records to gauge data - to account for lack of data on the upper tail of the flood peak distribution - can reduce the uncertainty in Flood Frequency Analysis (FFA) by over 50% (Lam et al. 2017a). With the expectation that there will be more extreme events as a result of climate change, palaeoflood records can only provide a more robust FFA and provide less uncertainty of what to expect with climate change. FFA are used in flood risk planning and management, typically for estimating the magnitude of the 1% Annual Exceedance Probability (AEP) design flood and its flood extent mapping.

What has happened before can happen again. Palaeoflood records can be used to increase flood awareness in locations where extreme floods may be perceived as unlikely. With increasing magnitude and/or frequency of extreme rainfall, tropical cyclones, and storm surges, palaeoflood records can be a proxy for community to perceive extreme events associated with climate change. Flood markers are increasingly used in places to remind the community of past extreme floods (see example in Figure 2). Flood markers for palaeofloods can be introduced to create awareness and help educate the community of possible extreme events in the future, similar to those events from the past. This can be an important aspect for flood risk management, through educating and communicating the risk to the community.

Figure 2. Flood markers in St. George on the bank of the Balonne River in Queensland (Source: Author)

Conclusions

The aim of this paper is to highlight that contemporary extreme events are not necessarily “unprecedented”. As Baker (2008) noted, the role for palaeoflood hydrology is to ‘aid humankind in its anticipation of flood hazards’ and ‘help us realise that reliable science exists to counter the claims … that such events are “unprecedented”’. Importantly, palaeoflood records has a role to play in waterway and flood management especially in the context of climate change. These events are likely to get worse in the context of climate change. And palaeoclimate data can and should be used to help us anticipate these natural hazards and reduce the Black Swan effect. With climate change, some may argue that the past is no longer relevant for the uncertain future, but physical evidence can provide reliable information to guide us about what extremes to expect from nature.

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