Time-series analysis of extreme rainfall and flood events in two water catchments of Eastern New South Wales shows an indicative link to Gleissberg 87 yr cycles

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Abstract

Two sites in adjacent catchments located in eastern NSW provide hydrological data over 200 years since European settlement: (a) height of the Hawkesbury River at Windsor, within the Sydney Basin (HR); (b) level of the ephemeral Lake George, sited 100 km inland (LG). HR has experienced 43 moderate to major floods since 1799 with the timing of floods grouping into approximate 40-year segments of greater or lesser flood frequency. LG has a reconstructed history of annual levels (Short et al, 2020) which shows obvious spacings with range 50 to 80 years. Three features are clear. The close correlation in time between HR floods, and the deep LG records, in separate hydrological catchments, suggests that these were not random occurrences. The sunspot record shows clear correlation in timing of occurrence (but not of amplitudes) of anomalously weak sunspot maxima with high rainfall/flood-prone segments. High sunspot maxima are associated with dryer 40 yr segments. Both datasets yield meaningful spectra via Lomb-Scargle spectral analysis (the data lengths being too short for reliable Fourier spectra). These power spectra show maxima at periods 82-88 yr (HR) and 80 yr (LG). Subsidiary peaks at periods 50, 30, 20and 11 yr appear on both. These peaks align with the first three of the six named periodicities in solar activity; the Schwabe(11yr); Hale (22yr) and the Gleissberg (87 yr) periodicities. These three periodicities are present in the sunspot record from1609 CE, and in the cosmogenic (Be and C) record of the past 50+ kyr where high sunspot activity correlates with low cosmic radiation and high total solar insolation (TSI). In particular HR for 1810-20 CE and LG for 1819-20 CE coincide with the last portion of the sunspot Dalton Minimum, the last of the "Little Ice Ages" experienced worldwide. The timing of HR floods correlates closely with La Nina events, and a subset correlates with solar cycle terminators described by Leamon et al (2021). We believe it is significant that a subset of terminators associated with dryer segments also approximate a pattern consistent with the 87 yr Gleissberg cycle. We conclude that just as solar cycle terminators appear to have predictive value for La Nina events, recognition of the Gleissberg cycle may have predictive value for ˜80 yr cycles of flood-prone and drought-prone times.

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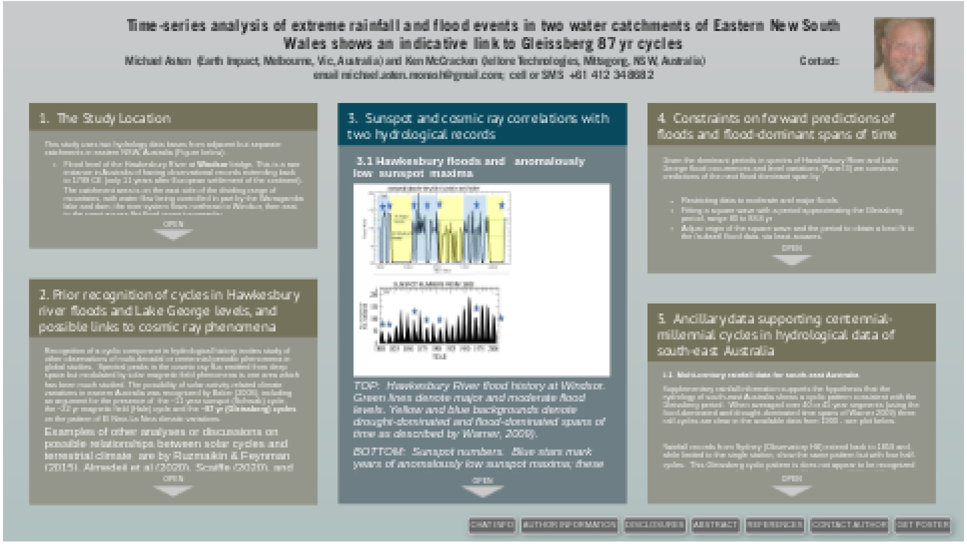

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1. THE STUDY LOCATION

This study uses two hydrology data bases from adjacent but separate catchments in eastern NSW, Australia (Figure below).

- Flood level of the Hawkesbury River at **Windsor** bridge. This is a rare instance in Australia of having observational records extending back to 1799 CE (only 11 years after European settlement of the continent). The catchment area is on the east side of the dividing range of mountains, with water flow being controlled in part by the Warragamba lake and dam; the river system flows northeast to Windsor, then east to the coast across flat flood-prone topography
-
- Depth levels of **Lake George**, an ephemeral lake located on the west side of the diving range, 100 km inland from the coast. Depth records extend back to 1820 CE.

On a multi-decadal scale the occurrence of major floods on the Hawkesbury river shows correlation with the major peaks in depth of Lake George. We analyse the spectra of these multi-decadal variations with the aim of improving estimates of relative probability of floods as a function of time, with obvious potential benefits for agriculture, urban water supplies and human safety.

We recognize that floods reflect high rainfall in a given season, while lake levels represent inflow, outflow, evaporation and seepage over multiple years, hence these parameters are not precisely comparable with rainfall. However this paper demonstrates that informative comparisons can be made when considering multi-decadal variations.

2. PRIOR RECOGNITION OF CYCLES IN HAWKESBURY RIVER FLOODS AND LAKE GEORGE LEVELS, AND POSSIBLE LINKS TO COSMIC RAY PHENOMENA

Recognition of a cyclic component in hydrological history invites study of other observations of multi-decadal or centennial periodic phenomena in global studies. Spectral peaks in the cosmic ray flux emitted from deep space but modulated by solar magnetic field phenomena is one area which has been much studied. The possibility of solar activity-related climate variations in eastern Australia was recognized by Baker (2008), including an argument for the presence of the ~11 year sunspot (Schwab) cycle, the ~22 yr magnetic field (Hale) cycle and the **~87 yr (Gleissberg) cycles** on the pattern of El Nino-La Nina climatic variations.

Examples of other analyses or discussions on possible relationships between solar cycles and terrestrial climate are by Ruzmaikin & Feynman (2015), Almedeij et al (2020), Scaiffe (2020), and Leamon et al (2017, 2020, 2021). McCracken et al (2013,2014) list spectral maxima of cosmic ray flux observed at the top of the earth's atmosphere (as deduced from isotopic studies of 10Be and 14C). One such prominent peak is the **Gleissberg period of 87 yr.** While cosmic ray phenomena are obviously global, in this paper we consider only the local observations in south-east Australia. We do not address in this paper the question of possible physical mechanisms linking cosmic ray and hydrological phenomena.

Warner (2009) studied the flood records for the Hawkesbury river at Windsor and identified a series of break points in time separating alternate spans of approximate length 40 years between drought-dominated and flood-dominated flow regimes. These breakpoints are used by Infrastructure NSW (2019) to classify the pattern of minor, moderate and major floods on the Hawkesbury River, as below.

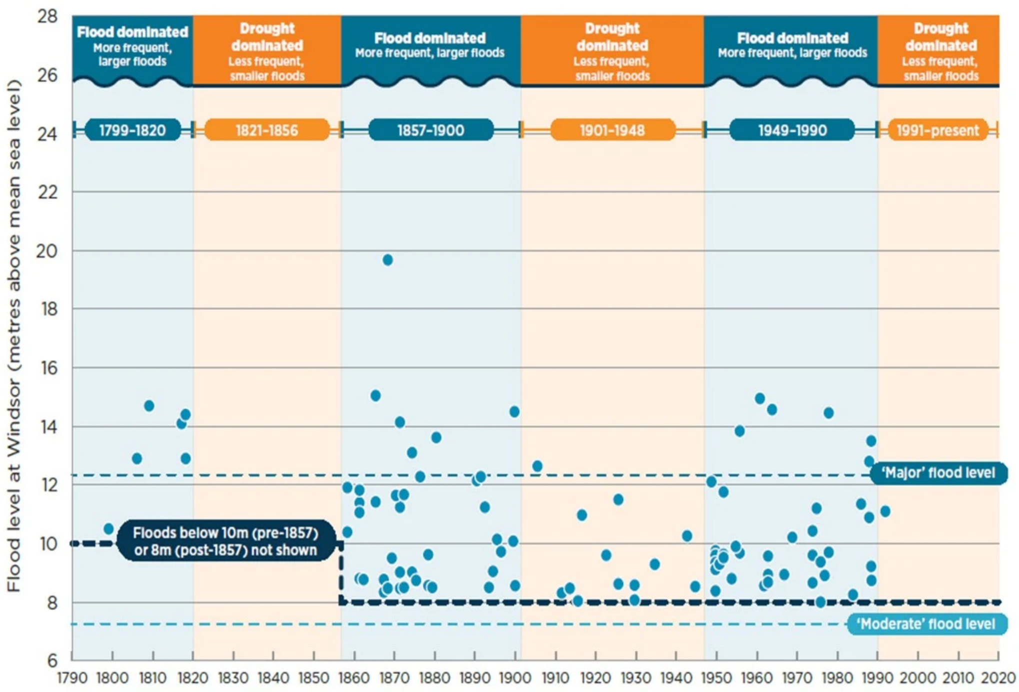
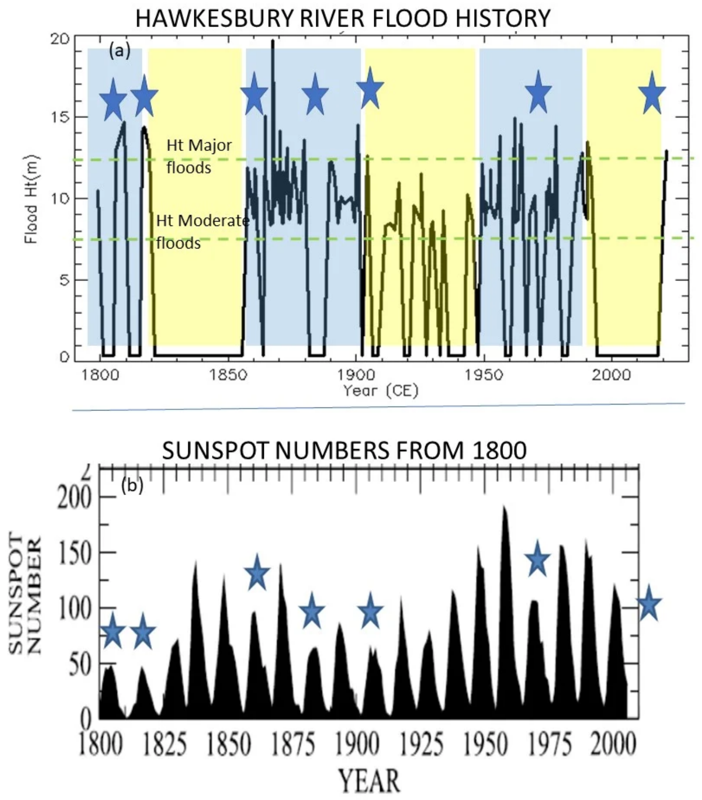


Figure 3 – Hawkesbury-Nepean floods at Windsor 1790 to present

3. SUNSPOT AND COSMIC RAY CORRELATIONS WITH TWO HYDROLOGICAL RECORDS

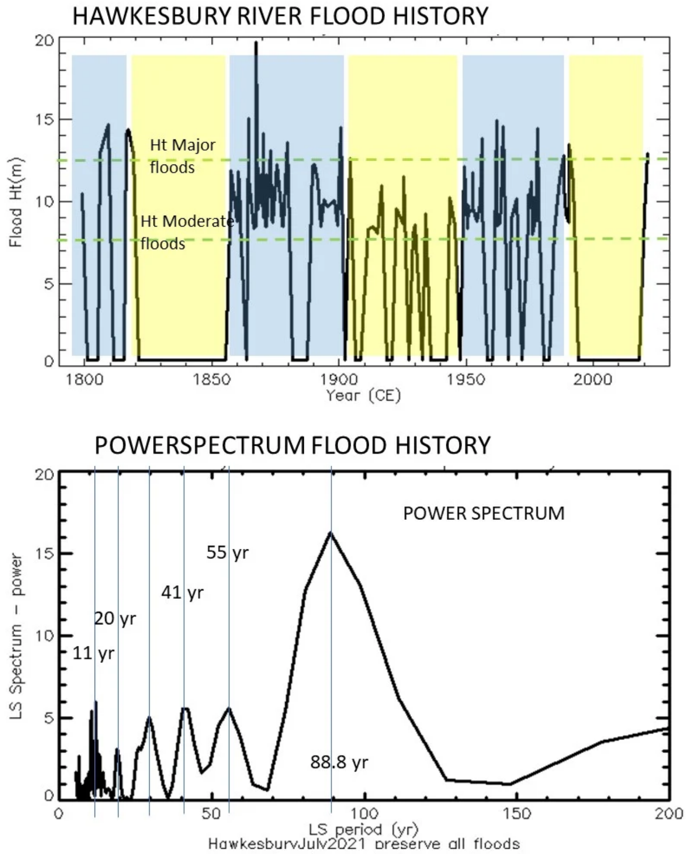
3.1 Hawkesbury floods and anomalously low sunspot maxima



TOP: Hawkesbury River flood history at Windsor. Green lines denote major and moderate flood levels. Yellow and blue backgrounds denote drought-dominated and flood-dominated spans of time as described by Warner, 2009).

BOTTOM: Sunspot numbers. Blue stars mark years of anomalously low sunspot maxima; these features visually correlate with flood-prone spans of time.

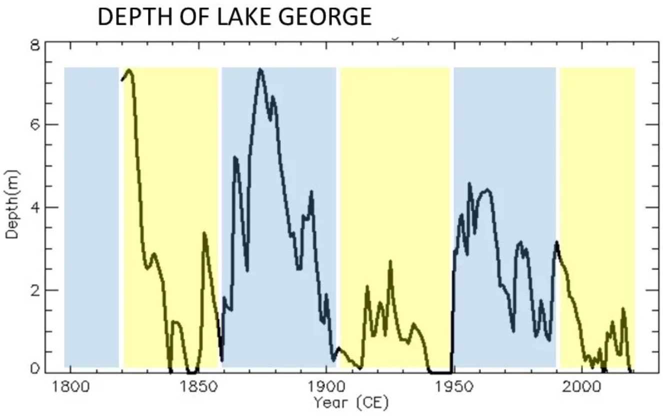
3.2 Lomb-Scargle spectrum of Hawkesbury floods

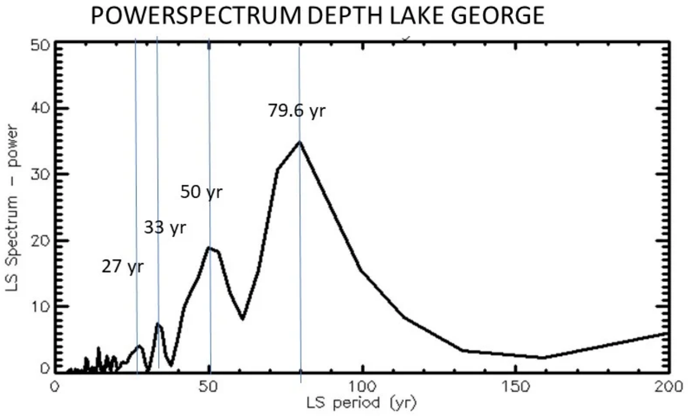


TOP: The flood levels recorded for the Hawkesbury River, NSW, at the Windsor Bridge. Times date from the start of European settlement (1799). The dashed green lines are the levels classified as for major and moderate floods. (Flood data supplied by Infrastructure NSW).

Bottom: Lomb-Scargle power spectrum of the plotted flood levels. There is a strong maximum at period 88.8 years. This is strongly suggestive of a correlation with the Gleissberg cycle period, as recorded in solar and cosmic ray phenomena.

3.3 Lomb-Scargle spectrum of Lake George levels





TOP: Lake George levels recorded from 1820. the cyclic trend is obvious, but a linear decresing trend over 200 years is also clear. The linear trend is of unknown origin. (Levels data from Short et al, 2020).

Bottom: Lomb-Scargle power spectrum of the lake levels. There is a strong maximum at period 80 years. This is strongly suggestive of a correlation with the Gleissberg cycle period recorded in solar and cosmic ray phenomena.

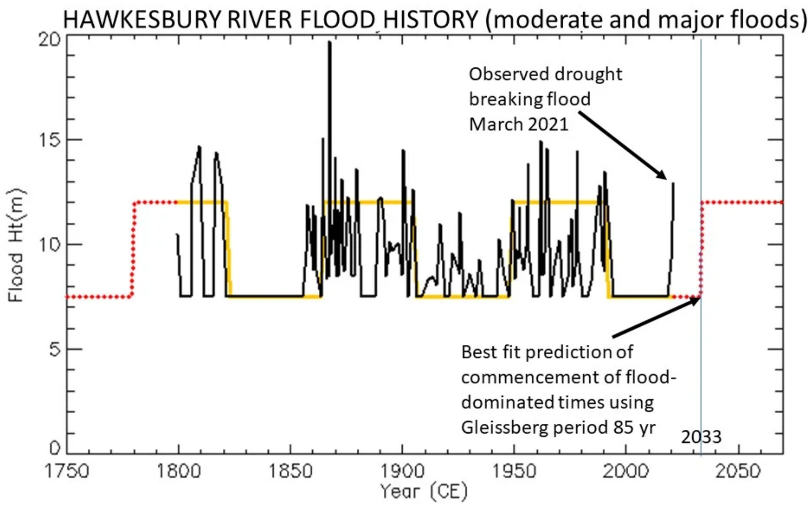
4. CONSTRAINTS ON FORWARD PREDICTIONS OF FLOODS AND FLOOD-DOMINANT SPANS OF TIME

Given the dominant periods in spectra of Hawkesbury River and Lake George flood occurrences and level variations (Panel 3) we constrain predictions of the next flood dominant span by

- Restricting data to moderate and major floods
- Fitting a square wave with a period approximating the Gleissberg period, range 80 to 88.8 yr
- Adjust origin of the square wave and the period to obtain a best fit to the (subset) flood data, via least-squares.

The plot below shows the best fit using a square-wave period of 85 yr, predicting the next flood-dominant span commencing in 2033. The Table and subsidiary plot show weaker fits using

- periods from **80 to 88.8 yr,** with associated
- predicted flood-dominant times from **2020 to 2042 CE.**



FIT OF A SQUARE WAVE of ~GLEISSBERG PERIOD TO TIMING OF HAWKESBURY RIVER MODERATE AND MAJOR FlOODS

Period	StdDev of fit	Predicted start of flood-dominated phase	
88.8	2.567	2042	
88	2.556	2038	
87	2.483	2042	
85	**2.471**	**2033**	**best fit**
83	2.56	2030	
80	2.574	2020	

Black: Hawkesbury River flood data. Orange: best fit square wave period 85 yr. Red: extrapolation of square wave earlier and later in time.

A second criterion for probability flood prediction

It is well established that the probability of seasonal rainfall above average in south-east Australia increases during La Nina events. However the predictability of La Nina events is contentious; Chen et al (2020) shows some success in using atmospheric and ocean data to extend predictability from 3-6 months to 8-10 months. In 2019 Luedescher et al (2019) used atmospheric and ocean data to predict occurrence of an El Nino event 12 months into the future; that prediction failed as the observed outcome was the 2020-21 La Nina event.

However Leamon et al (2017, 2020, 2021) used solar cycle and cosmic ray data to successfully forecast the 2020-21 La Nina event three years in advance. Their approach may provide means of prediction of La Nina events a decade into the future.

Note: a La Nina event raises the probability of a flood but does not predict a flood. The flood record for the Hawkesbury river shows for example a flood-free drought-dominated period 1990-2020 containing five La Nina events but only the last of these (2020-21) was associated with a Hawkesbury river flood.

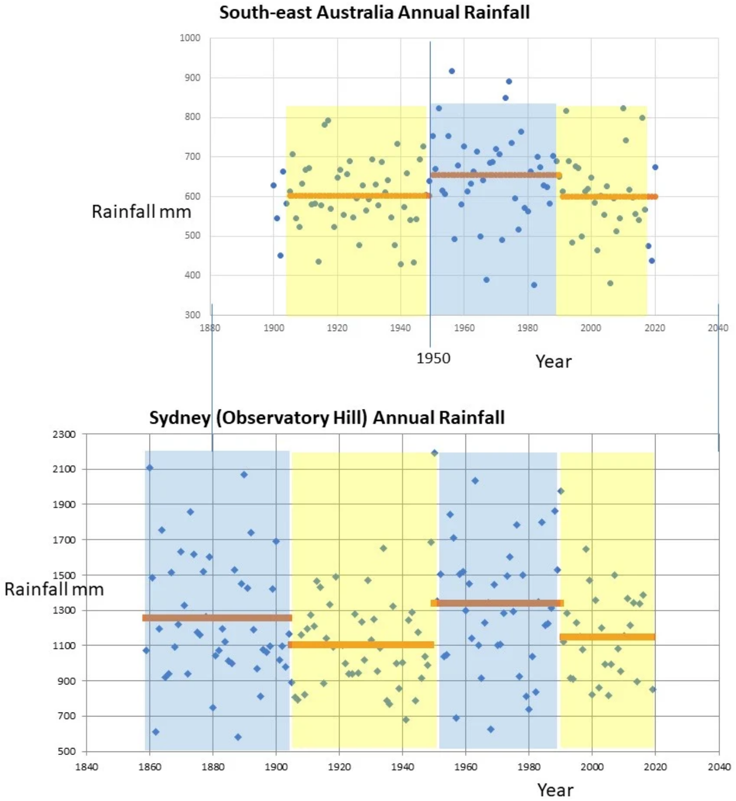
In summary, recognition of the cycles of flood-dominated drought-dominated time spans as a phenomenon associated with the Gleissberg cycle allows prediction of the next flood-dominant cycle in south-east Australia to commence within about a decade before or after 2033. It may have commenced already with the 2020-21 La Nina (currently extending into 2022). We may expect it to be influenced by future La Nina events, and note that predictions of Leamon et al are for La Nina events in 2020-21 (already validated), 2027-28 and 2032-33.

5. ANCILLARY DATA SUPPORTING CENTENNIAL-MILLENNIAL CYCLES IN HYDROLOGICAL DATA OF SOUTH-EAST AUSTRALIA

5.1 Multi-century rainfall data for south-east Australia

Supplementary rainfall information supports the hypothesis that the hydrology of south-east Australia shows a cyclic pattern consistent with the Gleissberg period. When averaged over 40 or 45 year segments (using the flood-dominated and drought-dominated time spans of Warner 2009) three half-cycles are clear in the available data from 1900 - see plot below.

Rainfall records from Sydney (Observatory Hill) extend back to 1859 and, while limited to the single station, show the same pattern but with four half-cycles. This Gleissberg cyclic pattern is does not appear to be recognized in current climate models (eg Bureau of Meteorology, 2020, p.23) where plots of rainfall from 1950 show a falling trend attributed to climate change. However if the ~85 yr cycle in rainfall data from earlier years, and flood data from 1800, is incorporated, there may be alternative results forthcoming from the rainfall model predictions.



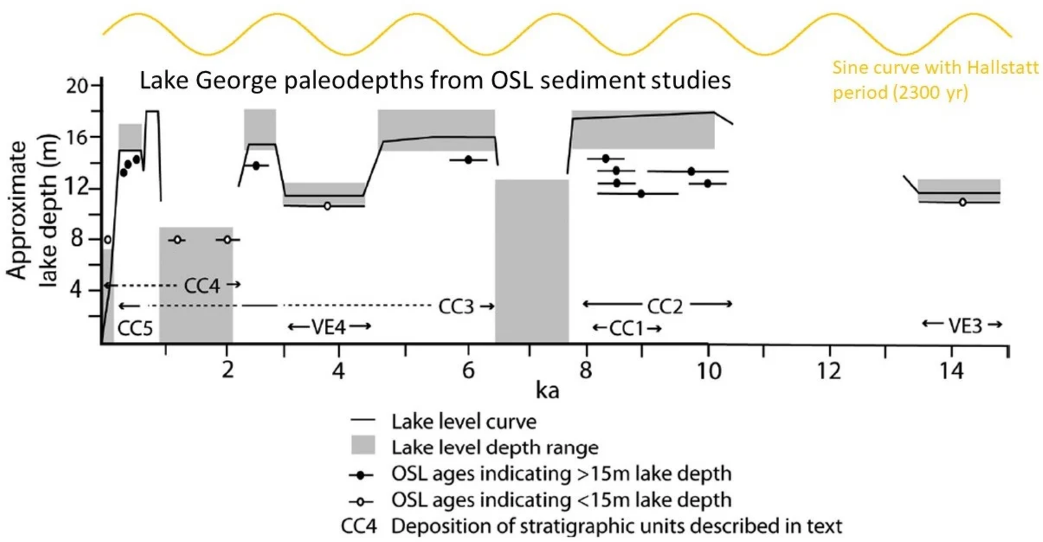
Annual rainfall for south-east Australia Top: South-east Australia average annual rainfall since 1900 (blue dots). Bottom: Sydney (Observatory Hill) records from commencement in 1859. Figures from Bureau of Meteorology.

Blue and yellow backgrounds are the flood dominant and drought-dominant time spans for NSW, as published by Warner (2009) and used by Infrastructure NSW (2019).

Brown lines are multi-decadal averages over drought-dominant and flood dominant years of the Hawkesbury River, years 1858-1900, 1901-1948, 1949-1990, 1991-2020.

5.2 Multi-millennia proxy data for the level of Lake George

The variations in level of Lake George have been studied using optically stimulated luminescence (OSL) chronology of recent lake shoreline sediments (Fitzsimmons and Barrow, 2010; McPhail et al, 2015; Jankowski et al, 2021). The figure below from Fitzsimmons and Barrow shows levels for the Holocene from 14000 years BP. Comparison with a sine curve of period 2300 yr (orange line superimposed on top of plot) suggests that level variations of the past ~5000 years show influence of that 2300 yr cycle; that periodicity corresponds with the Hallstatt cycle of the cosmic ray flux spectrum (McCracken et al, 2013, 2014). It is therefore another example of hydrological data suggesting a correlation with solar cycle periodic variations.



Lake George paleodepths from OSL sediment studies (from Fitzsimmons and Barrows, 2010). Orange line at top is added to illustrate a sine curve with the Hallstatt period of 2300 yr.

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DISCLOSURES

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AUTHOR INFORMATION

Michael Asten is a Professor of geophysics, now retired after 23 years in School of Earth Atmosphere and Environment, Monash University, Melbourne. He is a past-President of the ASEG, and served a recent three-year term as the AGC representative on the Australian Academy of Sciences UNCOVER Committee. He has published 208 scientific papers and has various research awards from the ASEG, BHP and CSIRO for innovations in electromagnetic, airborne gravity gradient and passive seismic methods. Using time-series analysis methods from past work he has also been researching for nine years the role of natural cycles in centennial and millennial global climate change; this work has been subject of eight papers at international conferences, the latest being the AGU in New Orleans, December 2021.

Ken McCracken, Fellow Aust. Acad.Sc. Research interests; cosmic ray modulation; solar energetic particle events; interplanetary magnetic field; geophysical techniques applied to deeply weathered terrains; cosmogenic radionuclide studies.

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Two sites in adjacent catchments located in eastern NSW provide hydrological data over 200 years since European settlement: (a) height of the Hawkesbury River at Windsor, within the Sydney Basin (HR); (b) level of the ephemeral Lake George, sited 100 km inland (LG). HR has experienced 43 moderate to major floods since 1799 with the timing of floods grouping into approximate 40-year segments of greater or lesser flood frequency. LG has a reconstructed history of annual levels (Short et al, 2020) which shows obvious spacings with range 50 to 80 years.

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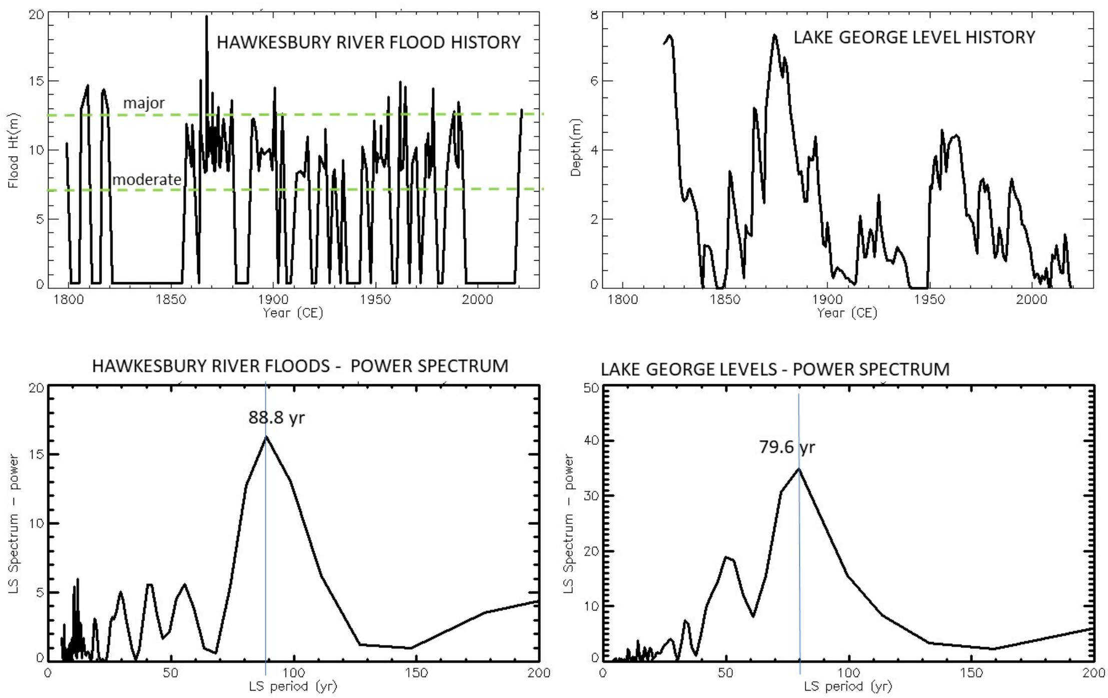

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