# Appendix 1. Data Description

On 21 September 2021, at 23:15 (UTC+0, or local time 9:15 am on 22 September 2021 in UTC+10), a mainshock with a local magnitude (ML) of 5.8 and a moment magnitude (MW) of 5.9 occurred. The mainshock epicentre was located at coordinates -37.506°, 146.402°, as determined through location inversions from stations that recorded the earthquake, and published by the Seismology Research Center (SRC). The SRC reported a preferred depth of approximately 12.7 km for the mainshock. Following the mainshock, aftershocks continued to occur in the near-source region, with approximately 1,000 earthquakes recorded within a 20 km radius during the initial 30 days. However, the earthquake records for the initial 48 hours may be incomplete. Ten temporary seismometers were deployed from 23 to 25 September to improve the recording of aftershocks and remained in the field for several weeks (Quigley et al., 2021). Despite the initial lack of near-source seismometers, the temporal and spatial distribution of the Woods Point earthquake and its subsequent aftershocks are relatively well-documented. The events were relocated by the SRC after the recordings, providing a relatively complete and accurate record of the Woods Point aftershock sequences. The catalogue downloaded from the SRC contains parameters such as the occurrence time of events (i.e., year, month, day, hour, minute, and second), the location of events (i.e., latitude, longitude, and depth in km), and the magnitude of events in local magnitude format. However, for the purpose of comparing with global earthquakes, the local magnitude (ML) of events was converted to moment magnitude (MW) using Equation S1, provided below. This equation was obtained through personal communication with Trevor Allen from Geoscience Australia. The conversion method Trevor used was published in the 2023 National Seismic Hazard Assessment for Australia (Allen et al., 2023). Trevor used simulated data to create the regional ML-MW conversion for our dataset, considering the number of recording stations, the sensitivity of the recorded seismometers, and their distances from the earthquake’s hypocentre.

Equation S1

Where

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Figure S1. Simulated Mw and mean ML datasets generated by Trevor Allen using orthogonal distance regression with a second-order quadratic functional form. The Woods Point catalog, recorded using 2080 sensitivity seismometers by SRC, is based on local magnitude. For further details, see The 2023 National Seismic Hazard Assessment for Australia (Allen et al., 2023).

The conversion equation (Equation S1) influences the magnitude distribution, particularly by increasing the number of earthquakes with magnitudes between 2.0 and 4.0 (Figure S1). For earthquakes with local magnitudes below 4.0 (ML < 4.0), the converted Moment Magnitude (MW) values are more concentrated in the 2.0 to 4.0 range compared to their local magnitude (ML) counterparts. However, for earthquakes with local magnitudes greater than 4.0 (ML > 4.0), the converted MW values tend to be lower than their corresponding ML values. This shift in magnitude distribution affects the magnitude bin with the highest population, thereby impacting statistical property calculations, such as those used in the Gutenberg-Richter Law and magnitude completeness identification, when using the magnitude distribution method.

In addition to these magnitude considerations, the spatial extent of the catalogue will be defined within a 50 km and 20 km radius from the mainshock epicentre (from the SRC dataset). The spatial windows of aftershock sequences can be determined based on the scaling relationships outlined in the equations below (Gardner & Knopoff, 1974; van Stiphout et al., 2012; Mitsui et al., 2024):

Equation S2

indicates the magnitude of the mainshock, represents the distance between the aftershock’s hypocentre and the mainshock’s hypocentre (in km), and denotes the elapsed days since the mainshock occurred. It is important to note that the extent of the aftershock zone, as calculated by these empirical equations, represents only the spatial and temporal windows within which aftershock sequences are likely to exhibit distinctive spatial-temporal clustering properties (Gardner & Knopoff, 1974). For the 2021 Woods Point earthquake, the aftershock zone spanned approximately 51.692 km (using the moment magnitude) or 50.239 km (using the local magnitude) from the mainshock’s hypocentre (as per the SRC published location). Consequently, the catalogue with a 50 km radius from the mainshock’s epicentre encompasses the aftershock zone as defined by the empirical equation (Equation S2). As shown in the density map (Figure S2), the degree of event clustering decreases with increasing distance from the mainshock epicentre. Therefore, using a 20 km catalogue helps focus on the most clustered earthquakes in the near-source region.

For the temporal extension of the catalogue, the length of the time windows will vary depending on the intended research focus. Based on the empirical equation (Equation S2), which estimates the temporal extent of aftershock sequences, aftershocks may continue for approximately 840.4 days (using ML 5.8) to 846.6 days (using MW 5.9). The catalogue obtained from SRC is dated 7 August 2024 (UTC+10), meaning the 20 km catalogue for aftershock sequences spans from the mainshock to 7 August 2024 (UTC+10), covering a period of 1051 days, which is expected to encompass the entire period of aftershock sequences.

For the study of background seismicity (i.e., during the pre-mainshock stage), including aftershock duration, a wider catalogue (i.e., 50 km radius) is used to capture regional behaviour. This catalogue includes events occurring both before and after the mainshock. Given the increased seismic activity following the Thomson Reservoir filling project, which began in 1983, and its subsequent return to pre-filling levels by 2000, combined with the limitations in network coverage and epicentre location accuracy for small-magnitude events prior to the 1980s (Allen et al., 2000), we limit our analysis to events recorded from 2000 onward. For studies examining the statistical properties of aftershocks, the same spatial range of the catalogue used for background seismicity will be considered.

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Description automatically generated

Figure S. Earthquake Density Map (during the post-mainshock stage). The density map was calculated as follows: the map was divided into 300x300 rectangular grids, and the frequency of events per cell was counted. The density per cell is shown in colour based on the colour bar on the right-hand side. The red star indicates the location of the mainshock epicentre, and the green line circles represent the 20 km and 50 km radii from the mainshock epicentre, respectively.

# References

Allen, T. I., Griffin, J. D., Clark, D. J., Cummins, P. R., Ghasemi, H., & Ebrahimi, R. (2023). The 2023 National Seismic Hazard Assessment for Australia. <https://dx.doi.org/10.26186/148969>

Allen, T., Gibson, G., & Hill, C. (2000). The Thomson Reservoir-Triggered Earthquakes. In *The Australian Earthquake Engineering Society 2000 Annual Conference*.

Gardner, J. K., & Knopoff, L. (1974). Is the sequence of earthquakes in Southern California, with aftershocks removed, Poissonian? Bulletin of the Seismological Society of America, 64(5), 1363-1367. <https://doi.org/10.1785/BSSA0640051363>

Mitsui, Y., Utagawa, Y., & Miyamoto, A. (2024). Quantifying the expansion rates of aftershock zones for magnitude-7 class earthquakes around the Japanese archipelago. Progress in Earth and Planetary Science, 11(1), 33. <https://doi.org/10.1186/s40645-024-00638-7>

Quigley, M., Pascale, A., Clark, D., & Allen, T. (2021). Wednesday 22 September 2021 Mw 5.9 Woods Point earthquake – Information Sheet. Accessed at: <https://learningfromearthquakes.org/2021-09-22-australia/images/2021_09_22-australia/pdfs/REPORT_EQ_27_SEPT_2021_short.TA.pdf>

van Stiphout, T., Zhuang, J., & Marsan, D. (2012). Seismicity declustering. Community Online Resource for Statistical Seismicity Analysis. <https://doi.org/10.5078/corssa-52382934>. Available at [http://www.corssa.org](http://www.corssa.org/)