

# **The March 2021 Flood on the Hawkesbury-Nepean River: An opportunity to revisit the Flood-Dominated-Regime – Drought-Dominated-Regime Model**

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## **Key Points**

- The March 2021, 12.9 metre flood on the Hawkesbury-Nepean was not particularly unusual.
- The Flood Dominated Regime-Drought Dominated Regime model is a useful predictive tool.
- Similar or larger, frequent floods can be expected to begin occurring again within 10 or 20 years.
- The Warragamba catchment commonly delivers 50% or less of the water in any particular flood.
- The Sackville Bathtub is commonly fully inundated before Warragamba Dam begins to spill.
- Warragamba water typically only increases maximum flood depth in the Sackville Bathtub by 1 to 3 metres, but significantly prolongs the duration of that flood.
- Raising the Warragamba Dam Wall for flood-mitigation purposes is of questionable value.

## **Abstract**

The March 2021 flood on the Hawkesbury-Nepean River peaked at 12.9 metres at Windsor Bridge and was the first major flood to occur in this catchment since 1990. This one-in-ten-year flood resulted in the evacuation of several thousand people from the region surrounding the ‘Sackville Bathtub’ which remained inundated for several days. Memories of the many floods that occurred between 1950 and 1990 have faded and the impacts and consequences of this event surprised many residents of the greater Sydney region. The flood’s characteristics have renewed discussion about the utility of raising the Warragamba Dam wall for flood mitigation purposes. The potential benefits of this intervention are contested because the Sackville Bathtub was largely inundated before Warragamba Dam began spilling - water from the lower Nepean River (Wallacia to Castlereagh reach), the Grose River, Eastern Creek and South Creek had already ‘filled the bath’. Re-examination of instrumental rainfall and flood records for the Hawkesbury-Nepean area in the context of geological climate records (i.e. proxy records) indicates that the prolonged dry conditions of the last thirty-years is entirely consistent with the Flood-Dominated Regime - Drought-Dominated Regime model proposed by Robin Warner and co-workers in the 1970’s. If, as is expected, the periodicity of FDR-DDR cycle is maintained at its historic 80 to 100 year-long average then the Hawkesbury-Nepean catchment will return to a Flood-Dominated condition within ten to twenty years.

## **Keywords**

Warragamba Dam, ‘Raising the Wall’, FDR-DDR Model, Sackville Bathtub.

## **Introduction**

The March 2021 flood on the Hawkesbury-Nepean River was the first major flood to occur in this catchment since 1990, and was the first of any significance since the onset of a ‘Drought-Dominated Regime’ that began in the early 1990’s. The March flood peaked at 12.9 metres (Windsor Bridge), making it a one-in-ten-year recurrence interval event (c.f. SES 2015), and resulted in the evacuation of several thousand people (~3000). Many of the evacuees live in and around a region known as the ‘Sackville Bathtub’ which remained inundated for several days. The communities residing to the north of the river at North Richmond and Wilberforce were isolated for several days due to the floodwater submerging Richmond and Windsor Bridges as well as landslides, triggered by the flood-associated storms, which blocked the other main access road to this district.

## **Full Paper**

### *Hubble and Power – The March 2021 Hawkesbury-Nepean Flood and the FDR-DDR Model*

A 12.9 metre flood was probably not generally recognized to be a likely event by many current residents (~54,000), especially those people who have moved to the area since the early 1990's. Memories of the twelve major floods that occurred between 1950 and 1990 have faded (i.e. one every 3½ years, with five of the twelve larger than the March 2021 flood). Similarly, a widespread public misapprehension that flood mitigation is a function of Warragamba Dam led to a robust public disagreement between politicians (including Ministerial colleagues) arguing the merits of the question posed by some of the affected residents as to "Why were there no managed releases from Warragamba to reduce the impact of the flooding downstream of this dam?".

As is well-understood by the emergency management community, Warragamba is a water supply dam and state government legislation effectively prohibits significant water releases for flood management purposes. In any case, it is common for half of the flood water entering the Sackville Bathtub to be sourced from other parts of the catchment and it bypasses Warragamba Dam entirely (SES 2015). This was exactly the nature of the March 2021 flood and the Sackville Bathtub was inundated before Warragamba Dam began to spill (see figures below). While water sourced from the Warragamba Catchment was a very significant addition, it only raised the maximum level of the flood by two to three metres; the more significant effect was to prolong the flood's duration by several days with normal 'low-flows' re-established about a week after the flood peak.

The occurrence of the March 2021 flood has prompted us to re-examine the Hawkesbury-Nepean River's flood and rainfall record (cf. Hubble and Hughes 2005) in the context of the Flood Dominated Regime-Drought Dominated Regime Model (FDR\_DDR) proposed by Robin Warner and co-workers in the 1970's. In particular, the additional 15 years of rainfall data collected since the 2005 investigation extends the period of instrumental record and enables a more informative comparison to the longer-duration, geological indicators of climate and rainfall variation. Consideration of this information in the context of the prolonged droughts which have impacted eastern-Australia more generally over the last twenty years indicates that the behaviour of the Hawkesbury-Nepean River system during the twenty-first century has been entirely consistent with Warner's model. Indeed, the virtual absence of significant flows during the last thirty years was predicted by the model. This reinforces the predictive power of the FDR-DDR model; which provides an evidence-based context for: a) assessing the utility and efficacy of raising the Warragamba Dam wall for flood mitigation purposes and b) planning and managing the urbanized reaches of the river downstream of the dam.

## **Characteristics of the March 2021 Flood in the Context of Previous Events**

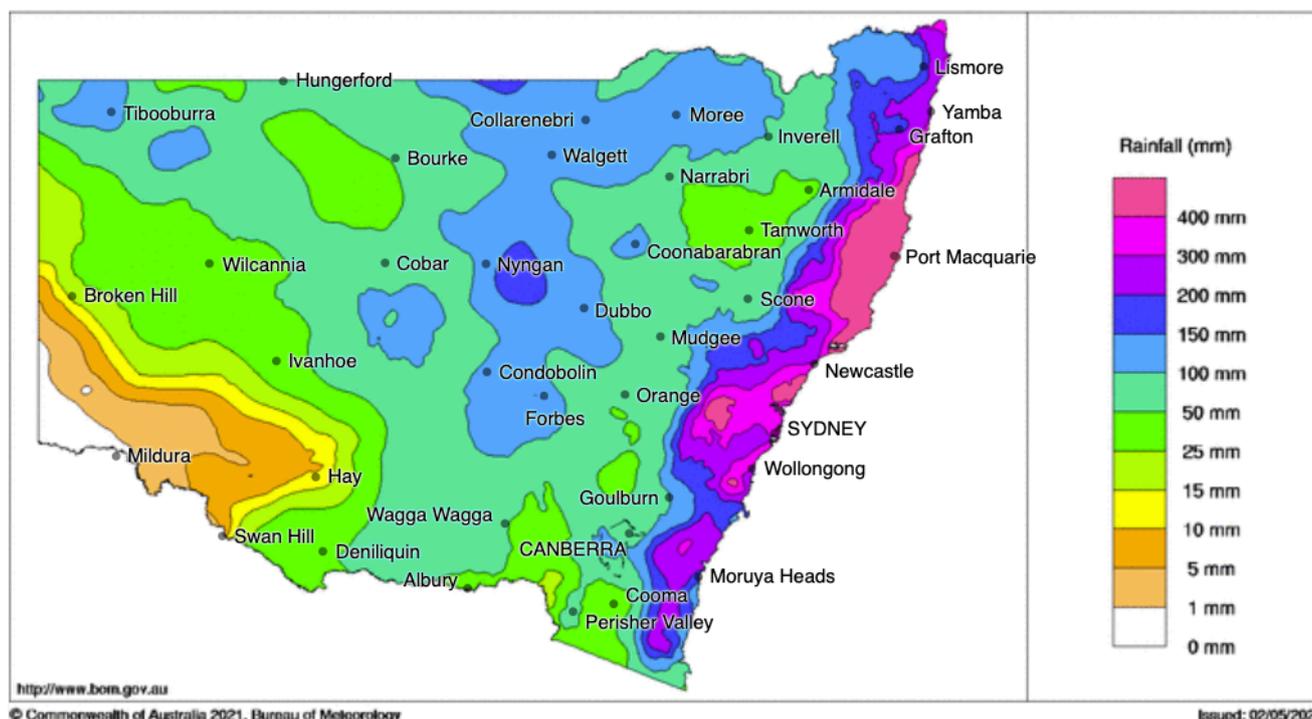
### *A Record Rainfall Event*

The following excerpts from the Bureau of Meteorology's report on the March 2021 rainfall event, elegantly and accurately capture the events which generated the March 2021 flood on the Hawkebury-Nepean River.

"The development and presence of a blocking high-pressure system in the Tasman Sea and a low-pressure system off north-west Australia fed a large volume of moist tropical air into eastern Australia. This caused extreme multi-day rainfall and significant flooding which affected many parts of eastern and central Australia from the 17th to the 26th March 2021. In these areas antecedent soil moisture, runoff and water storage levels were already relatively high due to the 2020–21 La Niña event." "Coastal New South Wales, including Sydney, experienced multiple days of heavy rainfall, with the week ending 24 March 2021 setting a record as the wettest week for the region since national daily records began in 1900. This caused flooding in most coastal catchments in New South Wales, adjacent parts of south-east Queensland and eastern Victoria" from about the 18<sup>th</sup> to the 28<sup>th</sup> of March (Quotes from B.O.M., 2021).

"The Hawkesbury–Nepean catchment in Sydney experienced its most significant flooding for more than 30 years due to a 7-day rainfall average of 265 mm which ranks as the third-highest on record" and generated the 15th highest flood on the instrumental record. "The most exceptional aspect of the event was the spatial extent of the heavy rainfall, both in coastal and inland areas. Almost the entire New South Wales coast

experienced heavy rain. This contrasts with typical rainfall patterns associated with either coastal lows or East Coast Lows, which normally bring heavy rain in a relatively small area near the southern flank of the low but are relatively dry to the north.” Similarly, “the occurrence of 5 consecutive rain days with each individual day total between 30 and 50 mm is exceptional and resulted in the record weekly totals in most locations on the east coast.” (Quotes from B.O.M., 2021).

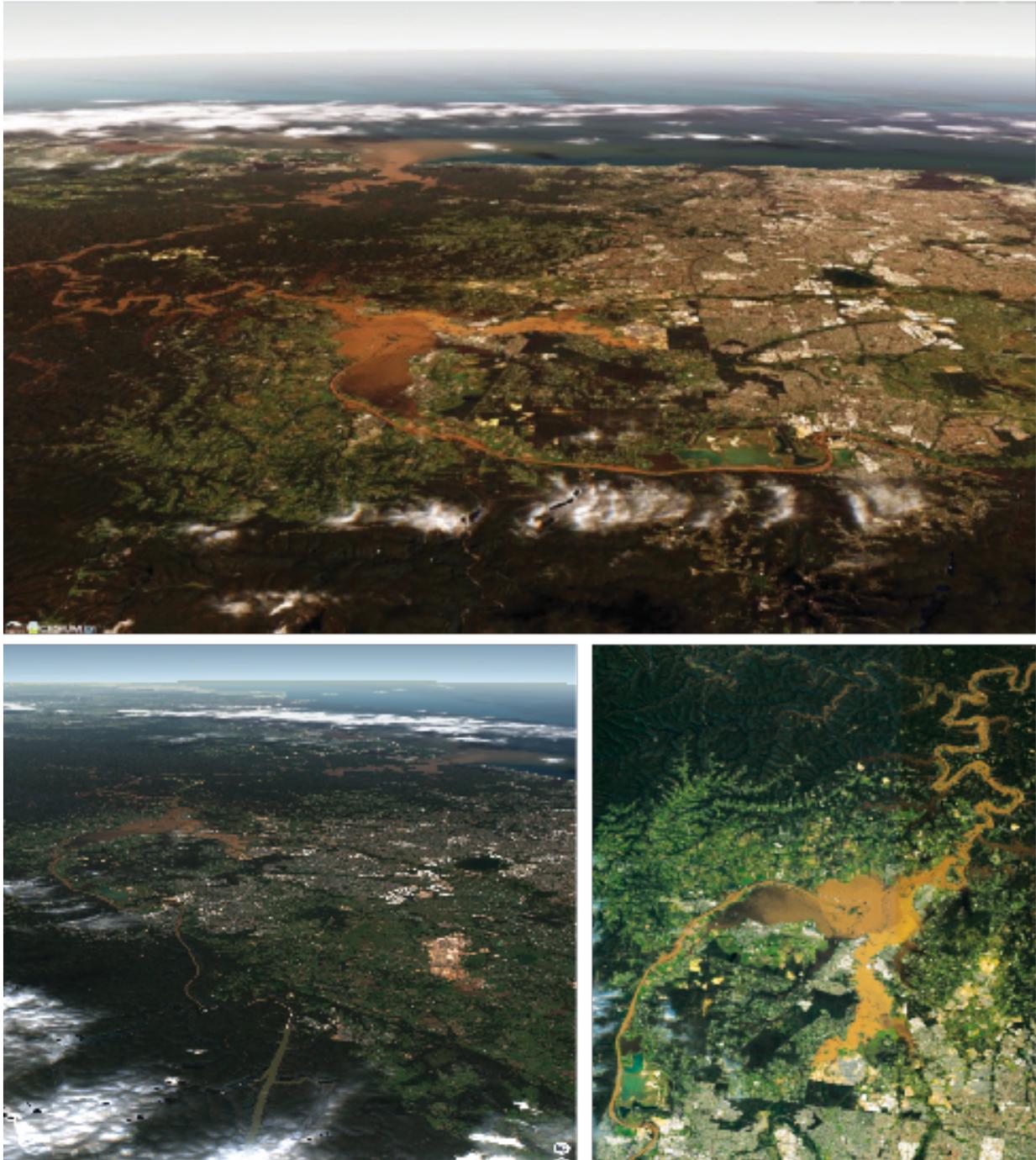


**Figure 1. Map of New South Wales showing total rainfall for the week ending March 23<sup>rd</sup> 2021. Image generated from the BoM website under a CC4 licence.**

Weather warnings (March 18th) and formal evacuation notices were issued by the Bureau of Meteorology and NSW SES (March 20th and 21st) for riverside residents living on the Hawkesbury-Nepean downstream of Penrith and around the so-called “Sackville Bathtub”. Weather forecasts undertaken by the Bureau of Meteorology’s numerical modelers accurately predicted the severity and duration of the rainfall event which provided confidence for the need, and several days’ notice, for preparations to be made by residents and first responders.

### *Filling The Sackville Bathtub*

A major factor that contributed to the generating the large volume of floodwater impounded in western Sydney between Penrith and Sackville is the so-called ‘Bathtub-Effect’. The Sackville ‘Bathtub’ is a natural, depression in the landscape that has formed very slowly over the last 100 million years due to plate tectonic processes associated with the formation of the Tasman Sea. ‘The Bathtub’ is floored by layers of mudstone rock that have been folded into a low-lying basin. This geological structure is surrounded by the high-standing, steep terrain and deep gorges eroded into the Sydney Sandstones of the Blue Mountains and the Hawkesbury River. At the transition between the bathtub’s mudstones and the gorges of the surrounding sandstone country the Hawkesbury-Nepean River’s channel narrows in width. This creates a pinch-point constriction that ‘partially blocks’ the river channel and impedes the river flow. In the same way that a bathplug sitting half-way over a plughole, slows down the draining of a bath, this natural pinch-point structure has backed-up floodwaters into the ‘Bathtub’. Similar constrictions ‘block’ the Nepean River near Theresa Park Weir in the Camden Valley and Wallacia Weir.



**Figure 2. Oblique and vertical views of the extent of flooding on the Hawkesbury-Nepean between Penrith (upper image bottom right) and the Tasman Sea (upper image, top left) after the storms finished (satellite images acquired at 11 a.m. March 25th 2021). Prominent in the images is the filled ‘Sackville Bathtub’ which shows several non-Warragamba sources of floodwater (i.e. differing shades of brown from South Creek (light brown), Grose and Nepean Rivers mid-to-dark brown; water exiting Warragamba Dam was relatively clear). Images prepared by Tom Hubble from the Cesiumlon website <http://maps.dea.ga.gov.au/#share=s-sv6J7VoOtox7KftCVe2CDlpdiaq> under a CC4 license.**

### *Could the Sackville Chokepoint Be Removed?*

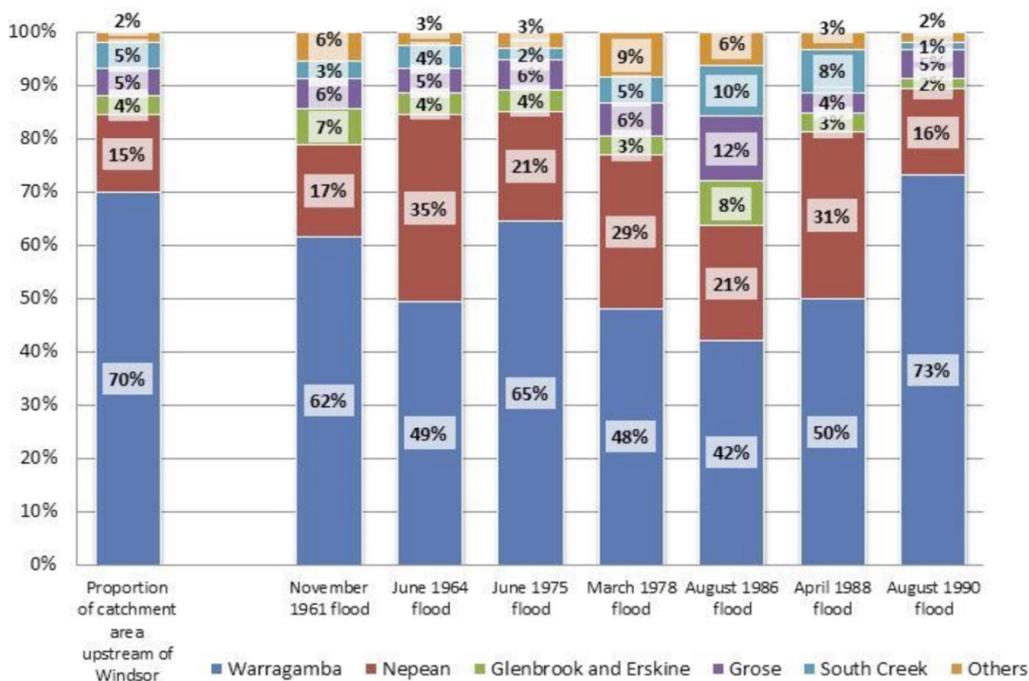
Significantly widening the river channel downstream of Sackville so that 'The Bathtub' could drain faster (and not fill up at all) is an idea that has been proposed in the past but due to the hard-rock nature of the gorge in which the soft-sediments of the river channel are 'inset', this potential remedy has received little serious consideration. The specific and somewhat unusual nature of the catchment including its size, the deeply incised hard-rock valleys, and the river channel gradients involved result in a delivery of such large volumes of

water during major floods (and almost inconceivable volumes during extreme events) that the drainage capacity of the channel downstream of the choke-points is totally overwhelmed. Unfortunately, it is not the low-flow channel that is the issue, it is the geometry and nature of the hard-rock gorge within which both the channel and its soft-sediment floodplain fill are sited that generates the choke-point.

‘Unblocking the pipe’ to the extent that flooding in the Windsor area would be negated as a problem is not an easy thing to do. The scale of the reconfiguration of the landscape that would be required to remove the Sackville choke-point downstream of Windsor would be of such large size that it would fail on economic grounds and any reasonable balancing of the environmental impact with the potential societal gain.

### The Progression of The March 2021 Flood

While the Warragamba Sub-Catchment represents approximately 70% of the total area of the Hawkesbury-Nepean Catchment it typically only delivers about half, and sometimes less than half, the water of any particular flood (see Figure 3). And, importantly, the Warragamba River flows also typically arrive relatively late to western Sydney and the Sackville Bathtub. This is partly because a) the source of the Warragamba flow is quite distant in comparison to locally sourced water from the Nepean River Catchment as well as the Grose River and Glenbrook, Erskine and South Creek Catchments which feed directly into the Sackville Bathtub; and b) some of the flow is intercepted by Warragamba Dam which must fill and spill before the Warragamba water contributes to the flood. In the case of the March 2021 flood the Dam was almost full, (the lake level was one metre below spilling), when the storms started, so the delay-time for Warragamba water to arrive in the Sackville Bathtub was mostly a consequence of the time required for the water to transit from the dam.



**Figure 3. Percentages of flood water contributed to particular Hawkesbury-Nepean River Floods by the catchments located upstream of Windsor that feed the Sackville Bathtub. Source SES Flood Plan (2015), provided under a CC4 license.**

Inspection of the rainfall and river gauge data, and particularly the Grose Wold and Castlereagh gauges, indicates that the Grose River as well as Glenbrook, Erskine and South Creeks supplied most of the Hawkesbury-Nepean River’s flow in the early stages of the flood prior to the point in time when Warragamba Dam began to spill between 3 pm and 4 pm on the afternoon of Saturday the 20<sup>th</sup> of March. It usually takes about six hours for water to travel from Warragamba Dam to Richmond Bridge and between 10 and 20 hours

for water to travel from Warragamba Dam to Windsor Bridge (SES 2015). Consequently, and as with many previous floods, the Sackville Bathtub was well inundated before the Warragamba Water arrived in the area.

Flows from the Warragamba constituted approximately half of the total volume of the flood water (WNSW 2021) delivered to the Sackville Bathtub and increased the flood’s level from moderate, somewhere between 10 m and 11 m at Windsor Bridge; to major at 12.9 metres at Windsor Bridge (see Figure 4). The other, and more significant effect of Warragamba flows on the March 2021 flood was to increase the residence time of floodwaters in the Sackville Bathtub and the duration of the flood more generally.

Detailed modelling will be required to apportion the relative contributions of the various sub-catchments to the size and duration of the flood, but preliminary consideration of the timing of the various flows also suggests that late-arriving water from the Upper Nepean Catchment in combination with significant flows into the Lower Hawkesbury from the Colo and MacDonald Rivers as well as Cattai Creek, all contributed to in delaying the fall of the river and prolonged the duration of the flood. Nevertheless, when the river gauge data for the March 2021 flood is considered in the context of previous floods such as the smaller August 1986 flood (11.3 m at Windsor Bridge and 42% Warragamba Flows) and the larger March 1978 flood (14.5 m at Windsor Bridge and 48% Warragamba flows) it is apparent that the area would definitely experienced a moderate (>10 m) and possibly a major flood (i.e. greater than 12 m at Windsor Bridge) even if Warragamba Dam had been lowered to 30% of its capacity (a totally unacceptable situation) prior to the rainfall event such that it could have intercepted and impounded all of the flows from the Warragamba Catchment due to the March Event – the 2000 GI capacity Dam received ~1300 GI during the flood of which ~1200 GI spilled.

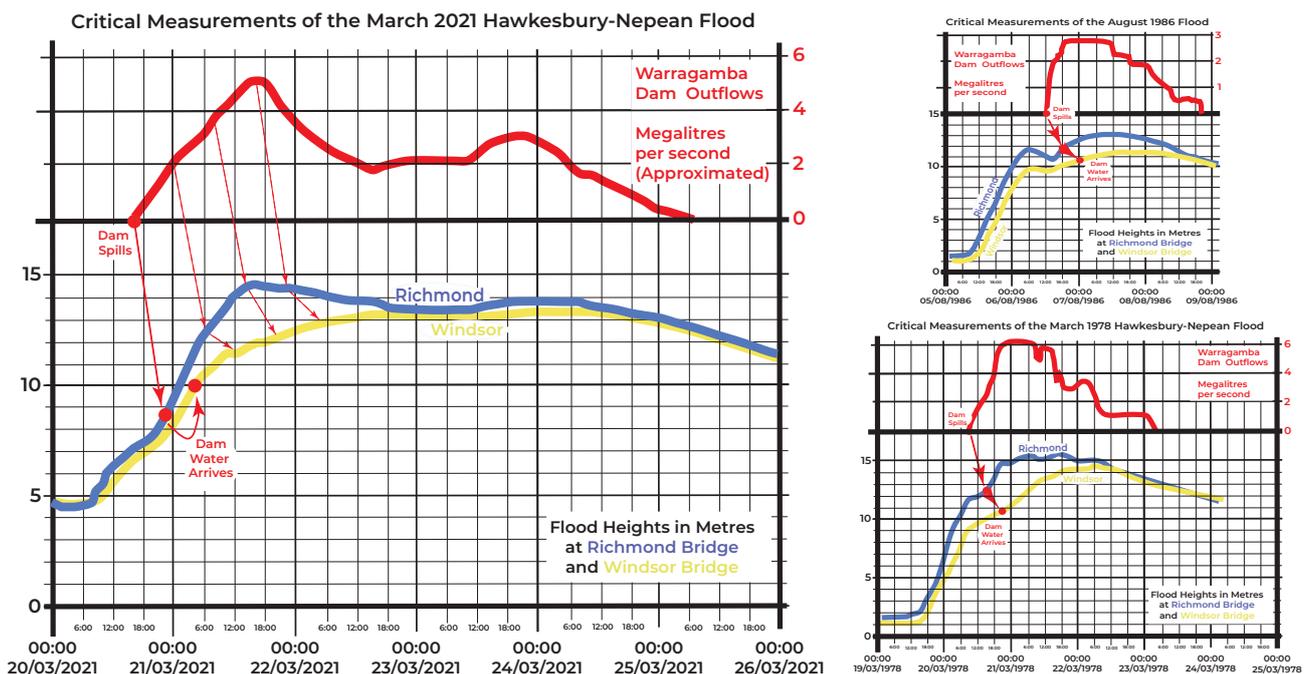


Figure 4. Progression and timing of Hawkesbury-Nepean River flood peaks at Richmond and Windsor in the context of the timing of filling and spilling of Warragamba Dam; March 2021, August 1986 and March 1978, Data from BOM 2021 and Infrastructure NSW Hawkesbury-Nepean Valley Regional Flood Study 2019.

### Revisiting the Flood-Dominated Regime and Drought Dominated Regime Model

The Flood-Dominated and Drought-Dominated Regime model for Hawkesbury-Nepean River flows was proposed by the University of Sydney’s Robin Warner in the mid-1970’s (e.g. Warner 1992, 2013). He suggested that this catchment cycles between two alternating hydro-climatic states of roughly equal duration with 40 to 50 years of dry weather with infrequent small floods are followed by 40 to 50 years of wet weather and frequent major floods. When it was proposed, the model was somewhat controversial because it is

roughly a century-long cycle. Only a few of us live long enough to witness the whole cycle and no one lives long enough to witness it twice. It was the return to Drought-Dominated conditions in 1990 that has proven this concept to be useful and worthwhile (e.g. Hubble and Rutherford 2010). It influenced the investigations and modelling undertaken in the Infrastructure NSW’s 2019 Hawkesbury-Nepean River Flood Study; and guided New South Wales’ SES preparations for flooding in Western Sydney. The superbly effective flood response efforts of the NSW SES and NSW Police during the March 2021 flood on the Hawkesbury-Nepean are in no small measure, a result of the application of the FDR-DDR principle in the modelling and analysis undertaken for the Flood Study and the development of the SES’s Flood Response Plan in 2015.

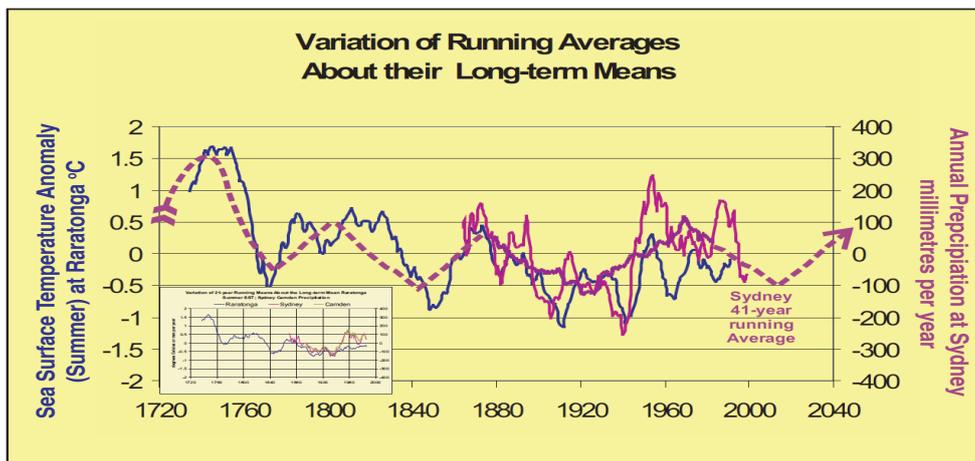


Figure 5. Hubble and Hughes’ (2005) forecasting and hindcasting of Sydney Hawkesbury-Nepean Catchment rainfall patterns on the basis of a proxy record of the Interdecadal Pacific Oscillation.

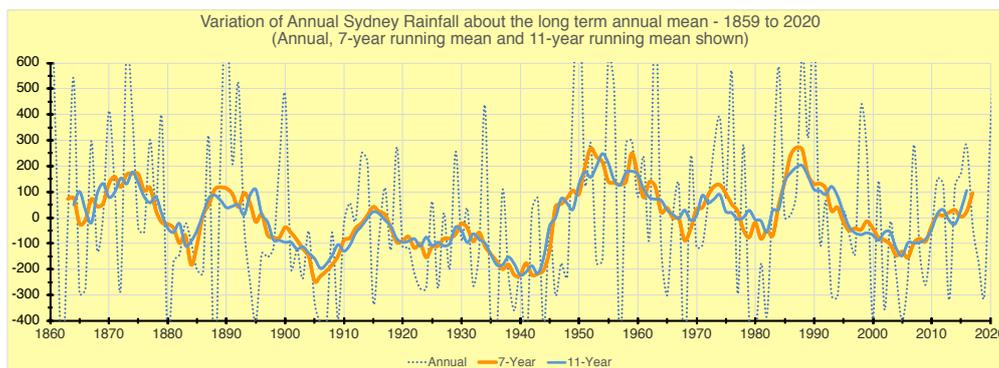


Figure 6. Annual Sydney Rainfall – note the minimum at 2006/7 and the recent increase.

Instrumental records of rainfall and river flows just weren’t long enough in the 1970’s to conclusively demonstrate that the FDR-DDR cycle was real – the longest relevant rainfall record is for Sydney which began in 1859 and now provides a complete record for the following 160 years. A 2005 study (Hubble and Hughes 2005) compared this record to a published proxy record of summer sea-surface temperature for the southern equatorial Pacific Ocean in the Cook Islands (Raratonga) and found a strikingly similar pattern of variation (see Figure 5). Statistical analysis for the common timespan indicates that these two records vary coherently at a variety of decadal and interdecadal periods within their common span of record suggesting that both phenomena are responding to the same drivers.

Spectral analysis of the individual records for the two sites also found that they vary at periods indicating strong resonance with periods expressed by the Southern Oscillation Index (El Niño/La Niña) and the Circum-Antarctic current. Prominent long-term fluctuations occur with periods of 80, 32, 16, 11 and 8 years at the Cook Islands and 40, 22, 12 and 7 years at Sydney. It is suggested that the longest period fluctuation (80 years) identified in the 270 year-long palaeoclimate record from Raratonga quite probably also presents at Sydney, but this is yet to be identified in the shorter, now 160 year-long record. It has also been established that FDR’s also coincide with high water levels in Lake George while DDR’s coincide with low levels, or no water at all, in Lake George (Short et al 2020).

Given that Warner’s 1998 inference (prediction) that a Drought Dominated Period began (was due) about 1990 has turned out to be accurate it follows that the use of the FDR-DDR concept as a predictive tool is reasonable and sensible. If the duration of individual FDR’s and DDR’s determined from historical instrumental and proxy records is maintained into the medium-term future then a switch from the current DDR back to wet conditions and the next FDR can be expected to occur at some point in the next ten to twenty years.

This means we should expect floods similar to the March 2021 flood and larger to occur relatively soon and much more frequently. If the historical records are to be taken to be a reliable guide of future behavior, we can expect moderate and major floods at Windsor Bridge to occur, on average, once every three or four years. It follows that: a) our recent lived-experience of the March 2021 flood suggests that there is an urgent need to reconsider the flood-risk faced by the affected communities; and b) the proposed raising of Warragamba Dam’s wall is probably not the “cure-all” that some proponents suggest it to be.

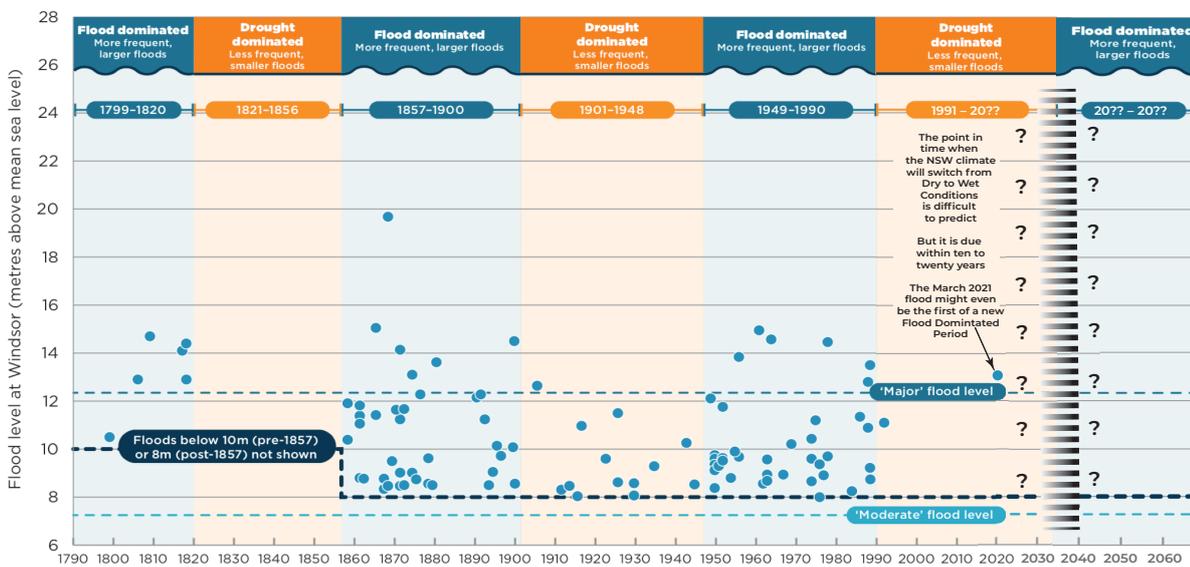


Figure 7. Flood heights at Windsor Bridge in the context of past and probable future Flood-Dominated Conditions. (Figure modified from SES NSW Hawkesbury-Nepean River Flood Response Plan, 2015).

## Acknowledgments

Robin Warner is thanked for his foresight, guidance and the many interesting discussions that influenced the preparation of this paper.

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