# Delivering Natural Flood Management (NFM): Working with geomorphic, vegetative and hydrological recovery in nature-based river management

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**Key Points**

- Natural Flood Management (NFM) uses natural processes to slow floods down, reduce their erosive power, and reduce flood risk.
- Most coastal rivers in New South Wales (NSW) had a noticeable decrease in flood wave celerity (speed) during the 2021 and 2022 floods compared to equivalent floods since the 1970s and earlier, but only some exhibited improved flood peak attenuation (reduction in flood peak height). Floods are slower but not lower.
- Changes in flood hydrology have occurred coincident with riparian vegetation regrowth (regreening) and geomorphic recovery over the last +30 years. These are the first signals that nature-based riparian management is counteracting some of the more severe hydrological effects of floods.
- The realisation of NFM is a tantalising one, but it will only be delivered if we re-examine current flood mitigation and adaption strategies and recognise and prioritise nature-based solutions as essential parts of the river management toolkit.
- On-ground tools include increasing roughness of instream and riparian zones, considering the utility of floodplains as flood mitigation assets and working at catchment-scales to (de)synchronise flood peak flows.

## Abstract

The 2021-2022 floods across eastern Australia highlighted the vulnerability of rivers to changing climate extremes. They are the costliest natural disaster in Australia’s recorded history with insured losses of ~$6.41 billion, well ahead of the 2019-20 ‘black summer’ bushfires (ICA 2022). By 2050, Australia’s annual extreme weather cost is likely to be $32.5 billion (ICA, 2022).

The 2022 NSW Government inquiry into the floods calls for implementation of “nature-based flood mitigation … using floodplains as assets … and letting watercourses largely flow naturally rather than implementing engineering barriers such as flood levees and mitigation schemes to stop floods” (O’Kane and Fuller, 2022). So, how do we achieve this?

Natural Flood Management (NFM) uses natural processes to slow floods down, reduce their erosive power, and reduce flood risk.

In coastal catchments of NSW we know that geomorphic, vegetative and hydrological recovery has been happening since the 1980s. In places where river recovery is most advanced, we are now seeing signals that NFM is also occurring. In these catchments there is a tantalising opportunity to implement large-scale NFM by value-adding on the solid foundations that are already in place. However, realising NFM on-the-ground is going to require that we apply all the nature-based tools we have in the toolbox. To deliver NFM, implementation will be required at channel and reach scales (increasing riparian and instream hydraulic roughness), valley-scales (using floodplains as sediment and water storage assets), and catchment-scales (desynchronisation of tributary and trunk stream flood peak flows).

In this paper I will demonstrate how NFM occurs and what now needs to happen to enhance river recovery and deliver flood mitigation to communities.

## Keywords

nature-based solutions; river recovery; river management; flood mitigation; work with nature

## Introduction

The 2021-2022 floods across eastern Australia brought into sharp focus the need to re-examine current flood mitigation and adaption strategies across the eastern states and NSW in particular. Traditional flood protection methods that aim to divert or rapidly flush flood waters through river systems often involve large, engineered structures such as detention basins, levees, bypasses, weirs, and dams that are costly to construct, expensive to maintain, and linked to poor environmental outcomes. Such measures also provide communities with a false sense of permanent protection from flooding (Birkholz et al., 2014).

Natural Flood Management (NFM), defined as a nature-based solution to flood mitigation, uses natural biophysical processes to slow floods down, reduce erosive power, and mitigate flood risk (Black et al., 2021; Dixon et al., 2016; Lane, 2017; Waylen et al. 2018; Wingfield et al., 2019). Put simply, NFM means working to enhance the structural (geomorphic), and vegetative roughness of rivers to achieve hydrological recovery (Figure 1).

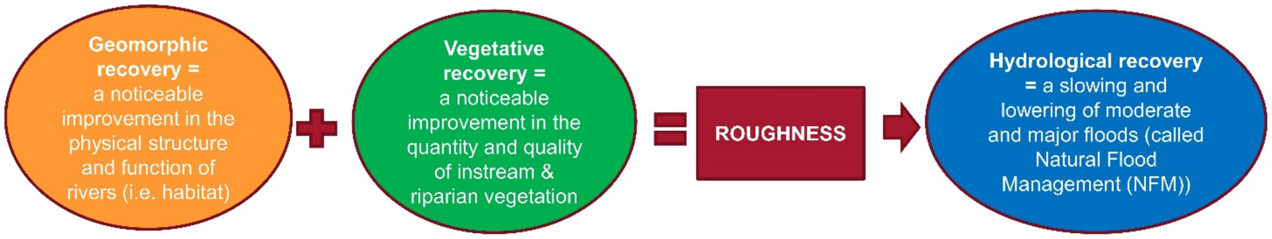

Figure 1. Conceptualising Natural Flood Management (NFM) in the context of river recovery.

NFM is a high-profile nature-based solution for achieving sustainable flood mitigation, while enhancing the health and resilience of riverine ecosystems (World Bank, 2018). NFM emphasises the rehabilitation of natural hydrological pathways, processes and corridors, providing important flood regulation services alongside water quality, biodiversity, aesthetic and cultural improvements (Iacob et al., 2014). On-ground rehabilitation includes returning vegetation roughness to rivers to slow flow down, delay flood peak travel time, reduce destructive stream power, and provide corridors for rivers to adjust and flood (Anderson et al., 2006; Asselman et al. 2022). Unfortunately, the river management sector in Australia has not yet considered the possibilities, nor realised the potential of at-scale implementation of NFM as an essential part of climate change adaption and flood mitigation strategies (e.g. Iacob et al., 2017; Kay et al., 2019).

It is clear that major and extreme flooding especially during severe La Niña events in eastern Australia, is no longer unprecedented. The 2021 and 2022 floods across eastern Australia were some of the largest, most widespread and costly on record, impacting thousands of people and businesses. Insured losses of the floods were costed at ~$6.41 billion (ICA, 2022). The effectiveness and suitability of current emergency planning, adaption, mitigation and response measures was severely tested (O'Kane and Fuller, 2022)

Despite the large-scale and devastating social and economic costs of these events, the geomorphic and vegetative effects of these floods were not as catastrophic as during similar events in the 1940s and 1950s where wholesale and ubiquitous erosion, deposition and channel change occurred. During the 2021-2022 floods many rivers 'held together' well and have shown remarkable structural resilience and recovery potential, with only in-channel reorganisation of sediments and vegetation thinning (Fryirs et al., 2023) (Figure 1).

In this paper, I use the 2021 and 2022 floods to investigate whether the hydrological behaviour of floods is changing in coastal catchments of NSW (Figure 2 for study area) and whether NFM signals are emerging. I then provide key recommendations for delivery of NFM in practice and on-the-ground.

## Methods

Signals of NFM can be detected relatively simply using two key measures – flood wave celerity and flood peak attenuation (see Fryirs et al., 2023 and Arash et al., 2023 for how to calculate).

Flood wave celerity is defined as the time taken for the peak of a flow or flood to pass between two points along a river channel. If flood wave celerity is decreasing over time, then the travel time between two gauges is increasing and floods are getting slower. We consider a change in flood wave celerity over time of ±0.5 m $s^{-1}$ to represent a noticeable change that is observable by people on-the-ground.

The attenuation of flow is the difference in peak stage height (or discharge) between two points along a river channel. If attenuation is increasing over time, then more flow is being placed in storage (e.g. on floodplains) between the two gauges and slowly being released as the flood peak passes and the flood wanes, reducing downstream peak stage height (and discharge). Flood peak attenuation not only reduces downstream peak discharges and water levels but can also slow down the propagation of the flood wave (Asselman et al., 2022). We consider a change in flood peak attenuation over time of ± 1 m to represent a noticeable change that is observable by people on-the-ground.

## Results

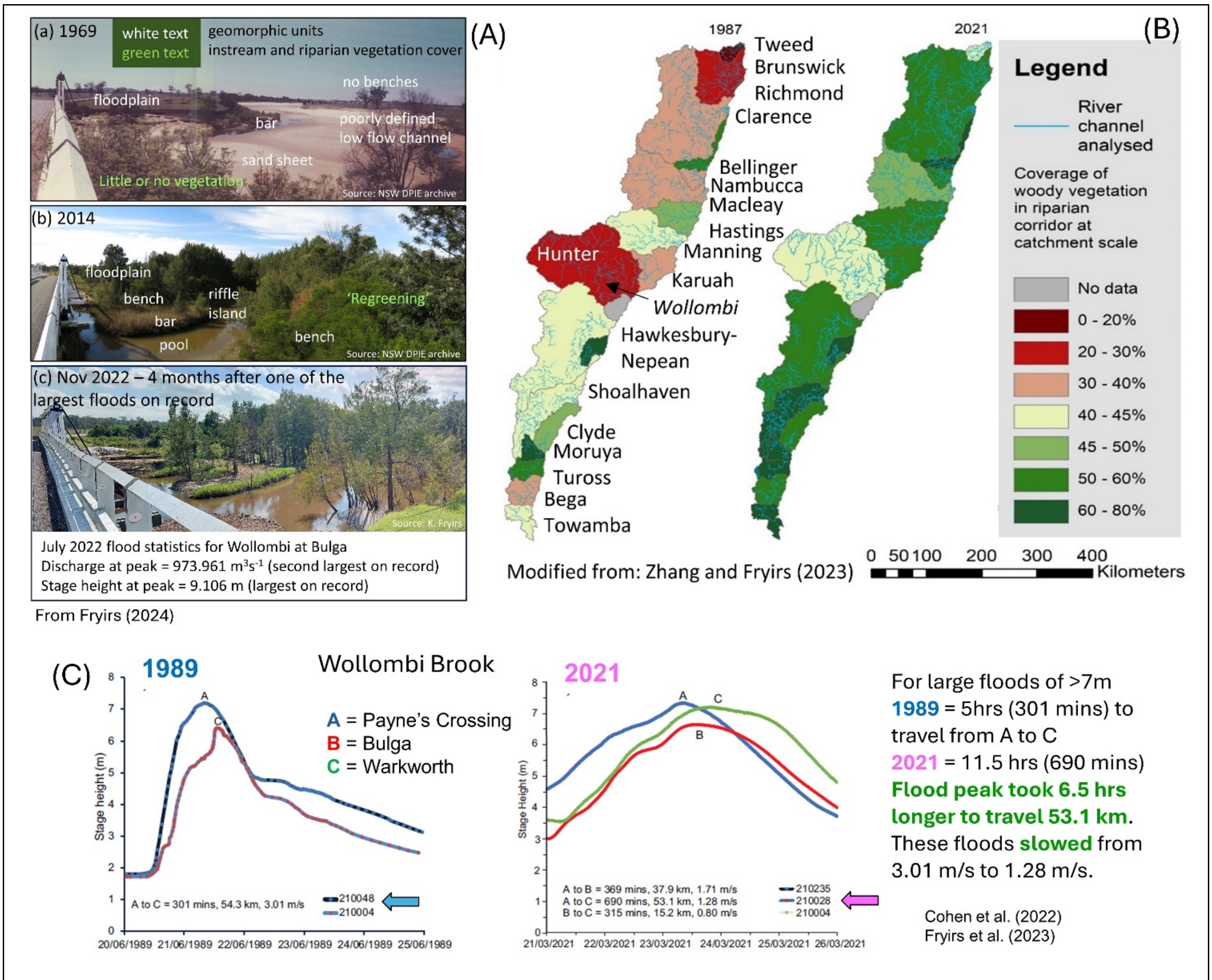

Figure 2. (A) Wollombi Brook at Bulga. Significant geomorphic and vegetative recovery has been occurring at this site for decades. This is creating both structural (geomorphic) and vegetative roughness that is having a significant effect on slowing flood flows and reducing their erosive potential – i.e. NFM is already occurring in this system (C). (B) shows the extent of regreening that has occurred in coastal catchment of NSW between 1987 and 2021.

### *Flood wave celerity and attenuation*

Of the 18 study rivers, 14 showed at least one decreasing trend in flood wave celerity between the recent floods and a comparable historical flood in the mid to late 1970s (Fryirs et al., 2023). Only the Richmond River and Hastings River on the North Coast and the Brogo River and Bega River on the South Coast did not have this trend. Changes in celerity for 11 of the 14 was noticeable with a decrease of more than -0.5 m $s^{-1}$ over time, along the Clarence, Macleay, Manning, Gloucester, Karuah, Williams, Lower Hunter, Pages, Wollombi, Nepean, and Shoalhaven Rivers. The decrease in celerity along the Hawkesbury River and Tuross River was not noticeable ($<0.5$ m $s^{-1}$). What is also evident is that the celerity of the recent floods was rarely extremely high ($>10$ m $s^{-1}$) compared to historical floods (Arash et al., 2023).

For several key examples, decreases in flood wave celerity (i.e. increases in flood travel time) have been pronounced (Fryirs et al., 2023). For the Manning River, Nepean River, Hunter River and Wollombi Brook, flood travel times have doubled since the 1970s, 1980s and 2000s. Peak flood travel time on the Manning River increased from 5 to 11 hours, on the Nepean from 8 to 14 hours, on the Hunter River from 4 to 19 hours, and on Wollombi Brook from 5 to 11.5 hours (Figure 2C). This has led to decreases in celerity in the order of 200 %, 175 %, 444 % and 230 %, respectively. The more recent 2021 and 2022 floods also produced hydrographs that have a flatter peak compared to the historical floods that have a more peaked, flashier shape (Figure 2C).

Noticeably more flood peak attenuation (i.e. the stage height at the downstream gauge has lowered over time by > 1 m) is not widely occurring and only displays a weak signal along 6 out of 18 rivers (33 %) (Fryirs et al., 2023). A noticeable change in attenuation of > 1 m was only found on the Clarence River, Manning River, Pages River, Wollombi Brook, Hawkesbury River and Nepean River when a comparison was made to much earlier floods in the 1950s and 1970s. Five of the 18 rivers analysed have noticeably less attenuation of -1 m, meaning that the stage height at the downstream gauge has increased over time (Arash et al., 2023).

### *Riparian 'regreening'*

The work of Cohen et al. (2022) and Zhang and Fryirs (2023) shows that along most rivers of coastal NSW, woody vegetation coverage was less than 20 % along the primary trunk streams and tributaries in the 1940s and 1950s (and as low as 6 % along the Hunter River). However, since 1987, riparian vegetation coverage has increased in various catchments by between 9 % and 51 % (Figure 2B). This is now commonly called the 'regreening' of rivers. This means that since the early-mid 20th century there has been a significant increase in riparian and instream roughness for these rivers (Figure 2A).

Decreases in celerity are generally occurring coeval with regreening (Arash et al., 2023). However, there is no clear coincidence between attenuation and regreening. This means that floods are generally getting slower, but not lower. We know that the effect of vegetation on attenuation can be more complex than on celerity. As flood waves slow down, flow can be backed up by in-channel vegetation and other forms of roughness which produces an increase in water level. If there is sufficient space and vegetation on floodplains, wetlands and riparian zones, water can be retained and stored for longer and slowly released to downstream channels, significantly reducing their erosive potential, delaying flood peaks and allowing for enhanced rewetting of floodplains (Lane, 2017).

## Recommendations for realising NFM

The results for the 2021-2022 floods hold significant promise for the possibility that NFM is possible across coastal catchments of NSW. The potential for realisation of large-scale NFM in these systems is a tantalising one. I now present several key recommendations for realising the potential of NFM (Figure 2).

### *Recommendation 1. Let the river do the work…..just help it along*

Working with the river means fully adopting a recovery-enhancement approach to river management (Fryirs et al., 2018, 2021; Fryirs, 2024; Fryirs and Brierley, 2021) and using nature-based solutions as a key part of a modern-day flood mitigation toolkit. Such an approach has been called on by the NSW Government Independent Inquiry into the floods (O'Kane and Fuller, 2022), backing many years of research into process-based river management (Beechie et al, 2010; Wheaton et al., 2019), fluvial corridors, and allowing rivers space to move, space to flood and space to erode (Buffin-Bélanger et al., 2015; Agnew and Fryirs, 2022).

Recommendation 27 of the Inquiry specifies the need to develop a "landscape restoration strategy…for nature-based flood mitigation and adaptation which would see large-scale native revegetation and wetland restoration", starting in the Northern Rivers region (O'Kane and Fuller, 2022, pg 36). Recommendation 20 specifies the need to consider "floodplains as an asset" including "letting watercourses largely flow naturally rather than implementing engineering barriers, such as flood levees, and mitigation schemes to stop floods" (O'Kane and Fuller, 2022, pg 30). It also specifies a reconsideration of land use planning and all development on floodplains.

The follow-on benefits of building flood resilient fluvial corridors using nature-based solutions means rivers can withstand more extreme floods and recover more quickly from them (Figure 3B) (Iacob et al., 2014; Deane et al., 2021), ultimately reducing the financial and environmental cost of river repair post-flooding.

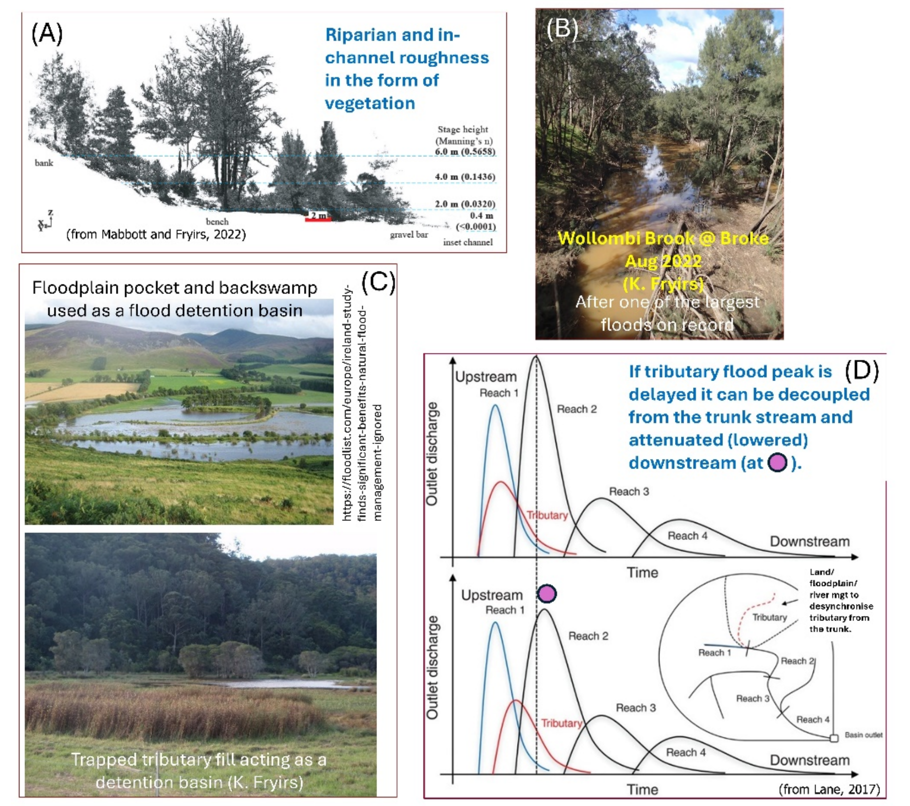

Figure 3. Recommendations for realising NFM. (A) Terrestrial Laser Scan (TLS) of in-channel and riparian vegetative roughness along Allyn River, Hunter catchment. (B) Example of the flood resilience brought about by having roughness in the river. From Wollombi Brook where the 2021-2022 floods were some of the largest on record. (A, B) are examples of channel and reach-scale NFM. (C) Types of floodplain assets to be considered as part of NFM at the valley-scale. (C) Concept of desynchronising tributaries to achieve flood attenuation as part of NFM. This requires working in tributary subcatchments at large scales.

## *Recommendation 2. Value-add on the geomorphic, vegetative and hydrological recovery that is already happening.*

In many coastal catchments of NSW there are already solid foundations from which to actively implement NFM in-practice and on-the-ground. Value-adding and enhancing the geomorphic and vegetative river recovery that is already occurring will be critical. Proactive, assisted, nature-based rehabilitation can be used to supplement and accelerate any trends to date, thereby maximising the mitigation potential of NFM.

To deliver NFM for minor, moderate and major floods will require implementation of management strategies at three scales (Figure 3):

*1) At channel and reach scales - increasing riparian and instream hydraulic roughness (Figure 3A, B).*

- Requires identification of where and what type of roughness needs to be established, where it needs to be enhanced and at what level/density.
- Requires consideration of how to use all the roughness tools in the toolkit. Roughness in river channels and riparian zones includes bank and channel roughness (roughness of vegetation and the geomorphic unit assemblage), and planform roughness (structural roughness created by configuration of the channel, e.g. meandering dissipates energy on bends and smaller channels dissipate energy over floodplains).

*2) At valley-scales - using floodplains as sediment and water storage assets (Figure 3C).*

- Requires understanding of what types of floodplain assets are available (e.g. palaeochannels, backswamps, trapped tributary fills, wetlands etc.), and where are they located, what their morphological and water detention/retention characteristics are, and how much 'critical mass' of floodplain assets is needed to achieve NFM.
- Requires consideration of how to increase the upstream storage of water in floodplain assets during floods. Improving the condition of floodplains and floodplain assets and allowing them to act as natural flood detention and release basins will be key.

*3) At (sub)catchment-scales – prioritising (sub)catchment rehabilitation to desynchronise tributary-trunk stream flood peak flows (Figure 3D).*

- Requires confirmation of the extent to which NFM is even possible for major and catastrophic floods. Understanding catchment-by-catchment drainage network structure and configuration as controls on flow and flood routing, and attenuation will be critical.
- Requires consideration of how to increase catchment infiltration, reduce runoff generation, and delay tributary discharge contributions to decouple tributary and trunk stream flood peaks using nature-based landuse planning and rehabilitation.

### *Recommendation 3. Work locally, but dramatically up-scale.*

So far, most of the regreening and geomorphic recovery that has occurred in coastal catchments of NSW is unassisted and passive, meaning they have occurred 'naturally' over the last few decades (Cohen et al., 2022; Erskine et al., 2009; Fryirs et al., 2018; Zhang and Fryirs, 2024a, b). Where assisted riparian revegetation and floodplain/wetland restoration has been implemented, it has tended to work at the local site or reach scale. Substantial up-scaling of current practice from reach-based projects to corridor and catchment-scale projects will be required to achieve NFM and flood mitigation at-scale (Figure 3D).

Work is required to prioritise efforts that are going to have the best return on investment (e.g. Dixon et al., 2016). Building corridors of flood mitigation and recovery will be critical (Agnew and Fryirs, 2022; Zhang and Fryirs, 2024a, b). Flood mitigation and river recovery is a catchment-scale, cumulative exercise and every reach counts towards a corridor. Thankfully in NSW, we already know a lot about the recovery potential of rivers (Fryirs et al., 2018) and databases such as River Styles (DPIE, 2021; Fryirs et al., 2021) have already been used to analyse where corridors of river recovery can be built (see Agnew and Fryirs, 2022; Agnew et al., 2022). The results are available Open Access at https://datasets.seed.nsw.gov.au/organization/macquarie-university meaning strategic decision-making and prioritisation can take place now. Of the >87,000 km stream length analysed in coastal catchments of NSW, 4,500 km could be immediately prioritised for rehabilitation to build corridors of river recovery and work towards delivering NFM (Agnew and Fryirs, 2022).

### *Recommendation 4. Know when to intervene and when to opt out*

The 2021-2022 floods have provided a "window of opportunity" to consider the evidence for NFM and the potential for its realisation by building on the river recovery that has been hard won over several decades (Fryirs et al. 2018). It is critical that the solid foundations that are currently in place are not 'lost' through reactive responses, poor practices, poor policy, or complacency.

One of the first tasks for delivering NFM to communities will involve a reality check. NFM is not a panacea and work is required to identify the types of floods that can be mitigated using NFM, and where NFM can realistically be delivered (or not). Proof-of-concept work is now underway to quantify and model the amount of roughness necessary to achieve different levels of flood mitigation, to identify where this roughness is needed in catchments, to identify the utility of floodplain assets as natural flood mitigators and whether it is even possible to (de)synchronise the storage and release time of water during floods and attenuate them (Black et al., 2021; Dixon et al., 2016; Iacob et al. 2017). The team at Macquarie University will be delivering these findings over the coming years as part of an ARC Linkage project (see Acknowledgements). Such analysis will hopefully assist managers to know; 1) when river recovery is happening and ***whether*** assisted or unassisted management is required to deliver NFM, 2) ***where***, ***when*** and ***how much*** to intervene to enhance river recovery to deliver NFM, and 3) when to ***opt-out*** of management and leave the river alone because it is already delivering NFM, and therefore redirect efforts elsewhere.

### *Recommendation 5. Get your stakeholder communications right*

Collective work will be needed on front facing, community, government and industry engagement to conceptualise NFM and its suitability and usability as a flood mitigation and adaptation tool in Australia, while challenging firmly held engineering philosophies of flood mitigation, flood risk and flood protection (e.g. Howgate and Kenyon, 2009; Iacob et al., 2017; Wells et al., 2019; Bark et al., 2021).

A challenge also lies in clearly explaining the processes that are occurring during NFM and the timeframes over which it can be realistically delivered. Contextualising the risk and the cost:benefit of implementation (or no action) will require careful consideration. For example, the slower but not lower message provides a communication and management conundrum when working with the realities of NFM. The question is; would communities prefer slower, less erosive floods that cause less damage and for which recovery time is shorter while accepting that the flood level may be higher and the water will reside in the system for longer?

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