From Fire to Flood: Lessons learnt from a nature-based reach-scale strategy after 22 years at Stockyard Creek

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Key Points

- Internationally, evidence-based research supports the use of natural flood management (NFM) or 'working with nature' to slow floods down, reduce erosive power and mitigate flood risk.
- Nature-based solutions such as engineered log jams (ELJs) can form an important tool in establishing resilient fluvial corridors.
- A structural assessment of 26 ELJs was undertaken following multiple disturbance events.
- Although 60% of the structures have experienced moderate to major change since construction, ELJ function is now largely replicated by the stabilising effects of established, mature vegetation on and around the structures as well as throughout the riparian zone.

Keywords

Large woody debris; Engineered log jam; Sand-bed stream, Rehabilitation, Nature-based Solution

Introduction

Internationally, evidence-based research supports the use of natural flood management (NFM) or 'working with nature' to slow floods down, reduce erosive power and mitigate flood risk (Fryirs et. al 2023). The concept of NFM utilises nature-based solutions (NBSs) such as revegetation to increase roughness at the catchment scale so rivers can withstand more extreme floods and recover more quickly when they occur (Iacob et al., 2014; Kumar et al., 2021). NFM is also estimated to have financial benefits by reducing the cost of river repair post-flood (Garvey & Paavola, 2022; Short et al., 2018).

NBSs such as engineered log jams can form an important tool in establishing resilient fluvial corridors. They can be used to influence the hydrology and morphology of a river reach while riparian vegetation recovers, and natural wood recruitment takes over as the primary means of wood input to the river (Daley and Brooks 2013). Decay is expected of ELJs, although the rate of decay should be low enough for recovering vegetation to become a stronger control on morphology. Condition inspections of ELJs in the Hunter River Catchment, suggest at a '*minimum the effective lifespan of a well designed and constructed ELJ is in the order of several decades and in some situations up to 50 years*' (Daley & Brooks, 2013). Structures that experience cyclical wetting and drying, are expected to have a shorter lifespan due to higher rates of decay.

To maximise NFM potential in an Australian context, we need to learn from previous riparian rehabilitation strategies so that we can better understand where riparian and instream vegetation needs to be established or enhanced as well as develop an understanding of the challenges, effort and timescales required to establish resilient fluvial corridors. This paper presents a case study looking at a long-term rehabilitation strategy involving native revegetation and the construction of 26 Engineered Log Jams (ELJs). The most recent assessment occurred following multiple disturbance events (Black Summer Bushfires and 2020-2022 Floods). It also presents key insights into the long-term management challenges and considerations of nature-based strategies in an Australian context.

Project Context

The study reach is situated on Stockyard Creek, a tributary of the Wollombi Brook and is located on Darkinjung, Awabakal and Wanaruah/Wonnarua Country of the Hunter Valley, NSW. The study reach has a partly-confined river style (Brierley & Fryirs, 2005) with a catchment area of ~ 35 km² and a total length of 2.2 km. The ELJ project involved the installation of 26 ELJs in April 2002 as a large scale Before-After-Control-Impact (BACI) design field experiment, with two separate treatment reaches (treatment A and treatment B), an upstream control reach and an external control in an adjacent valley. ELJ designs were based on structures implemented by Brooks et al. (2004), and also included the construction of experimental V-weir log sills (Brooks, 2006). The site was chosen for the project, as the observed morphology and land use history was considered to be representative of the post-european riverine landscape and the site has undergone a continuous native revegetation strategy since the late 1970's (Woodward B. pers. comm. 2013). Multiple topographic surveys of the reach were undertaken pre and post ELJ construction with geomorphic change detection recorded and analysed by Hughes (2014). A performance evaluation/structural assessment of the ELJs was undertaken in 2013 (Daley and Brooks, 2013).

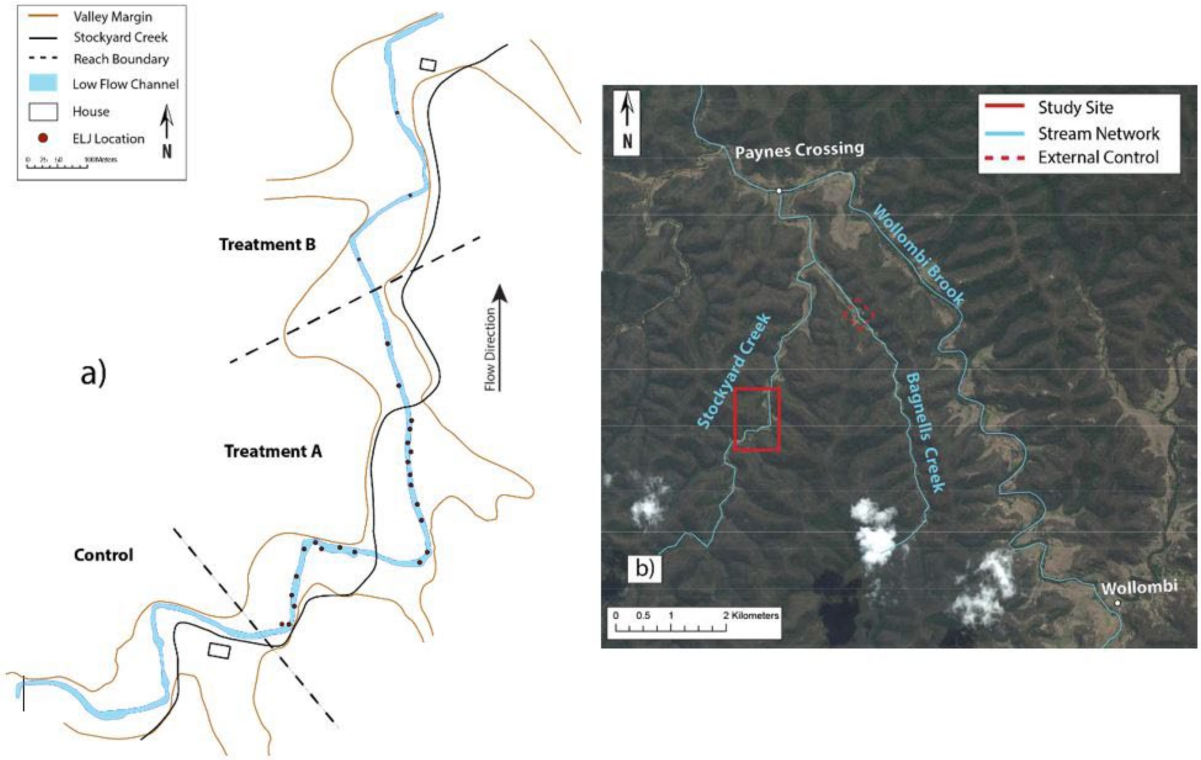


Figure 1. (a) Map of the study reach at Stockyard Creek indicating the layout of the BACI experimental design with ELJ locations. (b) Study site located within the Wollombi Valley.

Disturbance Events

The riparian buffer and majority of the ELJs at Stockyard Creek were burnt during the Black Summer Bushfires 2019/2020. The riparian corridor was mapped as experiencing medium burn severity (partial canopy scorch) by the Fire Extent and Severity Mapping (FESM) dataset for the event and the ridgeline surrounding the site was mapped as high to extreme burn severity (NSW DCCEEW, 2020). Shortly after the Black Summer Bushfires, the study reach experienced multiple high magnitude flood events throughout 2020 to 2022 resulting in geomorphic change within the reach. These events are estimated to be of similar magnitude to the flood events that occurred in the 1970s and 1980s (Fryirs et al, 2022) that resulted in wide-scale degradation throughout the Wollombi Catchment (Erskine 2008).

Figure 2. A photo of the scorched riparian corridor within the Study Reach following the Black Summer Bushfires 2019/2020. Photo provided by the landholder, Brian Woodward.

Methodology

A rapid structural assessment of the ELJs and study reach was undertaken within the reach to address landholder following the bushfires and floods. The rapid structural assessment was undertaken in June 2022. Each ELJ was inspected with GPS location, photos and parameters recorded via mobile device in Fieldmaps for ArcGIS. The methodology and parameters were collected as outlined in Daley and Brooks (2013) to ensure consistency with previous inspections. Daley and Brooks (2013) developed these parameters from current scientific understanding of the geomorphic and ecological benefits of ELJs. The structural assessment was undertaken by comparison of structural change since initial construction. Through the use of past photographic documentation and structural diagrams an assessment of the initial structural layout of each ELJ was determined. It was then assessed if change had occurred. The assessment also included recording additional metrics as a means of qualitatively assessing whether the structures were performing their intended engineering, geomorphic and ecological function. Table 1 and Table 2 outlines the parameters recorded in the field and the categorical decision classes used to assess the condition of the structure.

Table 1. Characteristics of ELJs and data structure for asset survey as developed by Daley and Brooks 2013.

Characteristic	Description
ID	ID determined at time of current survey
Stream	Stream at which ELJ is located
Construction ID	ID determined at time of construction
Latitude	GPS location (GDA94)
Longitude	
Elevation	
Structural Type	As described
Structural Function	Determined from surrounding geomorphic and hydrologic environment
Year	Year of ELJ construction
Width	Structural dimensions
Length	
Height	
Submersion (%)	Percentage of ELJ under water (i.e. under typical low flow conditions)
Condition of Structure	Qualitatively assessed on relative changes to the structure from the time of construction including structural failure, loss of log members and ballast material
Condition of Wood	Qualitatively assessed on degree of decay to wood pieces and extent of decay throughout structure. See condition matrix below (table 2)
Geomorphic Impacts	Description of geomorphic changes associated with structures on characteristics of pool scour, bar deposition, structural outflanking, deposition or scour of material within the structure, deposition around the structure and wood accretion
Biofilm Presence	Observed presence of microbial life on submerged component of ELJ
Vegetation Structure	Relative quantity of establishing vegetation on ELJ
Weed Ratio on Structure	Ratio of weed:native vegetation on ELJ
Weed Ratio Adjacent	Ratio of weed:native vegetation immediately surrounding the structure
Other	Other observable details relating to structure
Fire Affected	Yes/No

Table 2. Definition of the categories for the condition of structures (Daley & Brooks, 2013)

Characteristic	Description	Example of change
As built	Structurally unchanged since the time of construction	Loss of surficial ballast material
Minor Change	Possible changes do not affect the structural integrity or function of the ELJ	Realignment of racked members or timber piles; removal of timber piles; loss of surficial ballast material
Moderate Change	ELJ remains structurally sound and functionally effective, though potential loss of integrity may have occurred	Removal of racked members or timber piles; realignment of key members; structural realignment of ELJ
Major Change	Structural integrity and function has effectively been lost	Major structural failure or collapse; key logs entirely removed and no longer present; loss of entire ELJ

Results

Reach Morphology

The Black Summer Bushfires and subsequent floods triggered geomorphic change within Stockyard Creek, however, the stability and channel complexity identified by Hughes (2014) has been maintained and in some locations enhanced.

The channel displays pool-riffle morphology with deep, permanent pools located in association with ELJs either occurring:

- as scour pools downstream of where structures act as grade controls; or
- as elongated pools up and downstream of structures where the thalweg has progressed through fire damaged/burnt top and centre logs.

The bed and bank stability provided by the ELJs, combined with riparian vegetation establishment has allowed for vertical accretion, bench formation and deepening/narrowing of the low flow channel. This trajectory change in channel morphology is evidence of wholistic recovery which provides for ongoing stability even when ELJs no longer perform as stand-alone grade control structures (due to fire damage). From observations it seems the structural design intent of providing temporary stability and time for recovery has been met.

Riparian and In-channel Vegetation

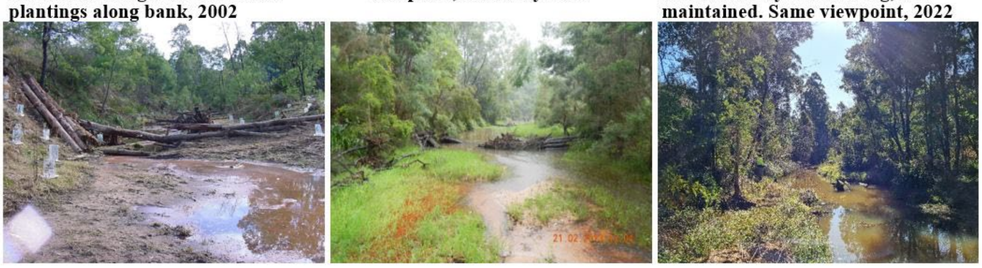
Vegetation throughout the reach is in good condition and dominated by a diversity of native species with vegetation successfully established on and surrounding the majority of ELJs (Figure 3). This may have helped to protect the ELJs from the impacts of fire with only the exposed logs burnt in the event. Natural system recovery is evident with geomorphic features (inset floodplain benches) stabilised by the recruitment of native species and natural accumulations of Small Woody Debris (SWD) (wood with a diameter <0.1m). Large Wood (LW) recruitment, defined as ≥ 10–20 cm diameter and 1–2 m long (Gippel et al. 1996; Wohl et al. 2016), from the riparian corridor was evident. Geomorphic features are still vegetated even after bushfire and multiple high magnitude flood events (Figure 3).

Structure Condition

Generally, the structures remained in place but unlike the 2013 structural inspection, majority of the ELJs have experienced some form of structural change because of the bushfires, with 60% experiencing moderate or major change. Log Sill structures experienced the most fire damage, with up to 94% of the Log Sills recorded as fire affected (Figure 4). The top sill/exposed logs were observed to be burnt by fire on majority of structures with the centre of the log sills now performing little influence on bed stability. Due to the sand-bed nature of Stockyard Creek, log sills were built spanning the channel cross-section (approx. 20-30m) to minimise outflanking with key-ins excavated deep into the top of bank. Although the centre of the log sills has been impacted by fire, the key-ins were barely visible and observed to be playing an important role in influencing bar and bank stability and general accretion recovery. The 2013 inspection recorded major change to two of the four Deflector Jams (DFJ) with the remaining two DFJ recorded as 'as-built' condition or having minor signs of change in the current inspection (Figure 4) with significant deposition and bar development identified in association with these ELJs. Anecdotal evidence suggests since the 2013 inspection, the structures within the reach, remained in good condition prior to the fires and despite the impacts of fire and flood, the wood from the ELJs has largely remained in place 22 years after construction. Log members that weren't burnt generally showed minor decay with evidence of biofilm, algae and aquatic flora existing on logs (Daley and Brooks, 2013. We do not believe the observed structural change due to fire damage represents a significant problem to the stability of the reach at Stockyard Creek, as the ELJ function is now largely replicated by the stabilising effect of vegetation on and around the structures.

View downstream to Deflector Jam during construction, 2002 | ELJ from same viewpoint, February 2013 | ELJ from same viewpoint, June 2022

View downstream to channel with constructed Log Sills and native plantings along bank, 2002 | Channel and ELJ from same viewpoint, February 2013 | Continuous pool on left bank maintained by elevated log, bar maintained. Same viewpoint, 2022



View downstream after completion of ELJ construction, 2002 | Channel from same viewpoint with significant regrowth, February 2013 | Channel from same viewpoint with significant regrowth, 2022

Figure 3. Example comparison photos taken during the structural assessment through time.

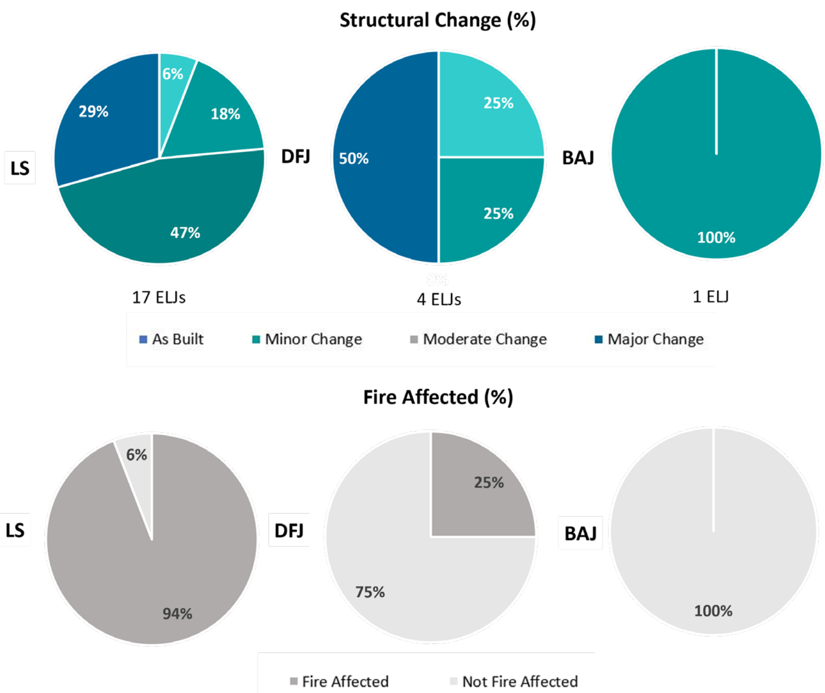


Figure 4. Proportion of structural change and recorded fire impacts for each structure type at Stockyard Creek – Log Sill (LS), Deflector Jam (DFJ), Bank Revetment Jam (BAJ).

So, what are the key lessons learnt from the assessment at Stockyard Creek?

Rehabilitation Strategy and Design

In the context of compounding natural disasters, it is apparent a reach-scale approach should be a focus when looking to rehabilitate or address issues in homogenous sandy systems rather than addressing localised issues at the source. If one structure fails in a natural disaster (as occurred at Stockyard Creek), the broader scale strategy can adjust to this change, reducing the need for costly repair works. A reach-scale focus also enables longitudinal change in gradient to be carefully considered and managed across multiple structures therefore reducing the risk of structural failure. However, we do acknowledge in the current rehabilitation landscape in NSW, working at the reach-scale can be challenging due to budgetary constraints and differing landownership.

The risk of structural failure is greater in partly-confined sandy systems, due to the dynamic nature of the bed and bank material. ELJs with the aim of inducing bed stability, were designed to span the entire channel width with extensive key-ins (excavated into top of bank) to reduce the risk of outflanking. The key-ins were observed to play a major role in enhancing long-term stability of the channel/bar development, with longitudinal bars forming in association with these structures. Deposition and revegetation on the key-ins also protected the underlying logs from fire impacts with only the exposed wood at the centre of structures burnt in the fire.

Out of the ELJ designs constructed at Stockyard Creek, one design is not considered more suitable than another with each type of ELJ performing a different function and resulting in different geomorphic outcomes. However, the failure of V-split weir and Log Pile Bed Control structures was observed in the study reach and at multiple sites throughout the Wollombi Catchment and are therefore not considered suitable for sand-bed streams.

ELJs are a NBSs used to stabilise and influence the hydrology of a river reach while the riparian zone recovers, and natural wood recruitment takes over as the primary means of wood input to the river. Therefore, the construction of ELJs should always be partnered with comprehensive riparian zone rehabilitation and stock exclusion to ensure vegetation successfully establishes on and surrounding the ELJs. If vegetation and deposition had not occurred on or surrounding the ELJs, fire and flood impacts may have been greater due to the exposed wood and lack of channel roughness.

Long-term Management of Nature-Based Solutions

The works at Stockyard Creek suggest ELJs within this setting can last up to 25 years plus and at this timescale vegetation starts to play a more important role in the stability of the waterway. This suggests ELJs can be seen as a long-term NBSs for establishing resilient fluvial corridors in an Australian context. The intention of most NBSs is to afford enough stability for vegetation or other natural species to take hold and add roughness/stability to the waterway. This requires the landholder to be onboard with the resulting geomorphic change and “messy river” that forms as a result. In the context of bushfire risk, this can be challenging as a revegetated riparian corridor potentially leads to a greater bushfire risk. Insights from the project at Stockyard Creek suggest for NBSs to be successful in the long term we need to support landholders in deciding:

- How to manage the increasing fuel load of a NBSs while also maintaining enough roughness for a resilient corridor
- When to intervene and maintain structures vs let nature take its course

The rapid structural assessment at Stockyard Creek, lead to the decision to not repair the ELJs and to let nature take its course.

NFM Considerations

Discussions, conversations and experiences surrounding the disturbance events that have occurred throughout NSW in the past decade have highlighted that if we want to up-scale projects like Stockyard Creek to achieve NFM, we need to:

- Overcome cross-tenure challenges and provide incentives for landholders to invest in and see the value in their riparian corridors.
- Expel long held vegetation myths and educate landholders in basic river behaviour and expected geomorphic change.
- Acknowledge the hard work of the landholder and the effort required to manage and maintain nature-based strategies through time including weed management, bushfire risk considerations and replacing/maintaining stock exclusion fencing.

Limitations and Future Investigations

The findings of this study are based on observations obtained through a rapid site inspection following a natural disaster with the aim of providing management advice to the landholder, however numerous detailed studies have been undertaken within the study reach that support the findings provided in this paper. Future investigations such as a repeat topographic survey, vegetation surveys and Terrestrial LiDAR surveys to determine roughness parameters would assist in providing a more quantitative analysis of outcomes achieved throughout the study reach.

Conclusion

Since the late 1970's the study site at Stockyard Creek has been transformed from an incised river system with actively eroding banks, to a geomorphically diverse system with near permanent pools and continuous riparian vegetation (Hughes, 2014). Although the ELJs have now become somewhat redundant in performing their bed stability function, we do not believe the observed structural change represents a significant problem to the stability of the reach. ELJ function is now largely replicated by the stabilising effect of vegetation on and around the structures as well as throughout the riparian zone. The ELJs have performed their intended function of decreasing bedload transport, increasing the height of the bed upstream, inducing channel constriction, deposition and scour, amplifying the pool-riffle sequence, and increasing bench height. Natural bed controls are now evident within the reach with natural wood recruitment now taking over as the primary means of wood input to the creek. The outcomes from the project at Stockyard Creek offer insights as to how to support landholders throughout the life cycle of a nature-based project, particularly when making the important decision of when to maintain nature-based assets following disturbance events or let nature take its course. It also offers insights into the effort and the potential timescale required to establish a resilient fluvial corridor in a partly-confined, sand-bed stream.

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