Post-fire erosion mitigation investigation and trial in the Warragamba drinking water catchment

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Key Points

- Rapid post-fire and flood erosion mitigation works involve many challenges in the design, planning and delivery stages.
- Installation and monitoring of 250 coir logs and 13 channel structures identified the importance of response timeframes, considering natural recovery potential, evaluating intervention disturbance and the value of a 'do nothing' approach.
- The trial erosion mitigation site had an estimated 11.2 T of sediment captured across a 9.5 ha area (118 T/km^2). Repeat monitoring detected a reduction in the accumulation of sediment over time, suggesting that the erosion rate was slowing, and the site was stabilising.

Abstract

During the 2019/2020 bushfire season, approximately 320,000 ha (35 per cent) of the Warragamba Catchment burnt and was closely followed by a widespread storm event from 7 to 10 February 2020, with approximately 400-500 mm of rain recorded. These combined events posed a raw water quality risk to Warragamba Dam. Soil Conservation Service (SCS) was engaged by WaterNSW to undertake a post-fire catchment investigation to identify areas of high risk to raw water quality, install trial erosion control structures at a priority site and complete monitoring of recovery across three sites. Overall, 250 coir logs and 13 mesh in-channel sediment capture structures were installed and monitored. Baseline monitoring occurred in September 2021 and follow-up monitoring was undertaken in May/June 2022 and November 2022 to review the performance of the erosion mitigation works and the vegetative and geomorphic recovery of the sites. The trial erosion mitigation site had an estimated 11.2 T of sediment captured across a 9.5 ha area (118 T/km^2) during the monitoring period, and monitoring detected a slowing rate of sediment capture over time indicating a reduced erosion rate. Monitoring across the three sites identified that by October 2022 (2.5 years post-fire) all sites had dense regrowth of ground and mid-storey species, re-establishing canopy cover and dense ground cover/leaf litter in most areas, except bare earth was still evident in areas identified as bare earth at 9 months post-fire. The outcomes of the erosion mitigation trial and monitoring program aimed to establish a knowledge-based approach for future post-fire response.

Keywords

Post-fire response, erosion mitigation, sediment capture, vegetation recovery, drinking water catchment

Introduction

During the 2019/2020 bushfire season, the Erskine Creek, Green Wattle Creek and Ruined Castle Fires burnt a combined area of approximately 320,000 ha in the Blue Mountains and Southern Highlands of NSW, totalling 35 per cent of the Warragamba Catchment. Following the "Black Summer" bushfires, a widespread storm event occurred from 7 to 10 February 2020 with approximately 400-500 mm of rain recorded within the catchment. These combined events posed a raw water quality risk to Warragamba Dam, which accounts for 80 per cent of Sydney's drinking water. Soil Conservation Service (SCS) was engaged by WaterNSW to undertake a post-fire catchment investigation to identify areas of high risk to raw water quality. Following initial catchment field inspections, key locations were proposed for the installation of erosion control structures and monitoring. The intention of the monitoring program was to record post-fire recovery/impacts in the Warragamba Catchment and the performance of erosion mitigation works. The outcomes of the monitoring program would establish a knowledge-based approach for future post-fire response. Post-fire erosion mitigation works and baseline monitoring were undertaken by SCS in September 2021. Follow-up monitoring was undertaken in May/June 2022 and November 2022 to review the performance of the erosion mitigation works and the vegetative and geomorphic recovery of the study sites.

Study Area

Three sites in the Warragamba Catchment were selected for the project as displayed in Figure 1 and listed in Table 1. The final sites were selected from a list of potential sites identified in the post-fire catchment assessment (SCS, 2020). These sites were considered to have the most prevalent ongoing impact from the 2019/20 fires and effectively represented a range of landscape settings in the Warragamba Catchment.

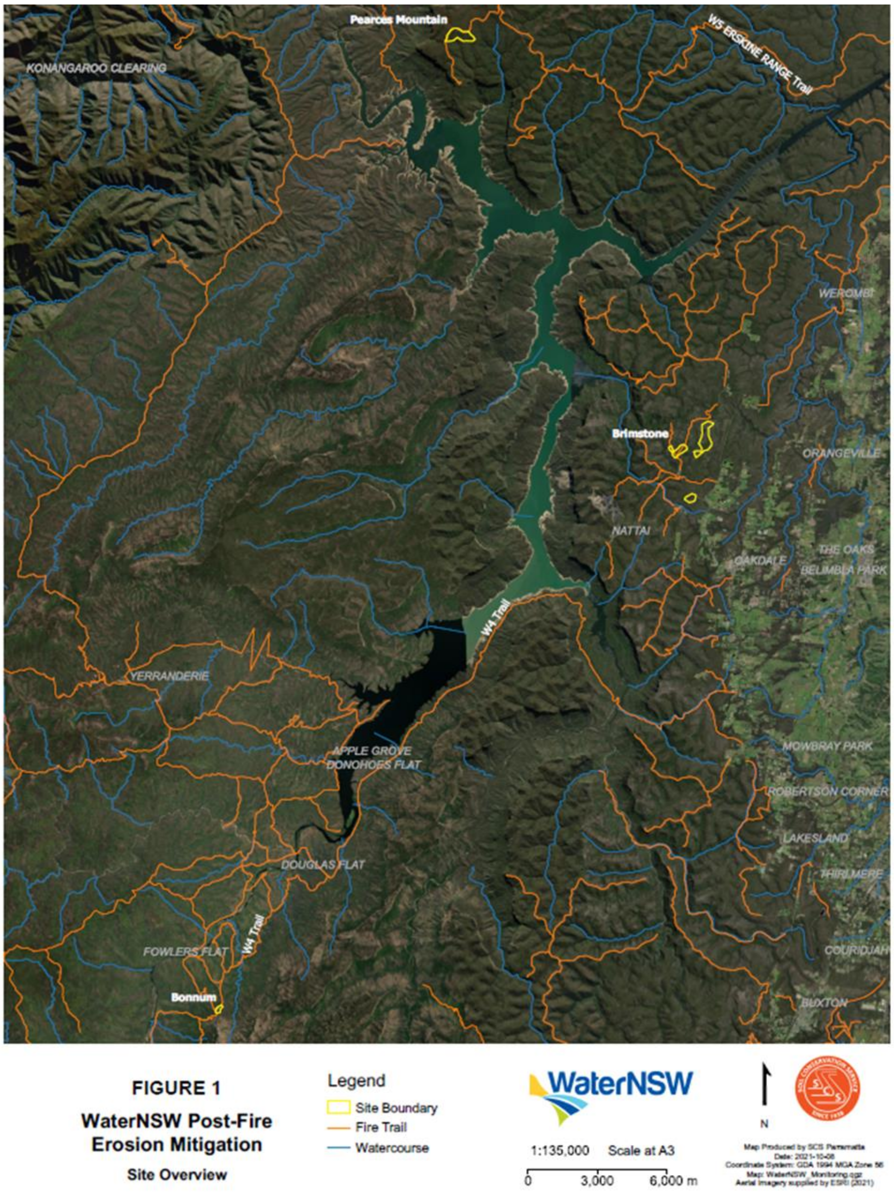


Figure 1. Overview of erosion mitigation and monitoring site locations

Table 1. Sites selected for the Post-Fire Erosion Mitigation project

Site	Type	Area	National Park/Tenure
Bonnum Pic	Intervention and Monitoring	6 ha	Nattai National Park (part Declared Wilderness)
Pearce's Mountain	Monitoring only	45 ha	Blue Mountains National Park
Brimstone	Monitoring only	21 ha, 12 ha, 52 ha	Burragorang State Conservation Area (part) Crown Land (part)

Methodology

Erosion Mitigation Structures

Previous studies by SCS considered the Warragamba Catchment context unique compared to many other examples of post-fire catchment response in Australia due to its World Heritage, Wilderness, Declared Special Area, and National Park status (SCS, 2020). As such, many erosion mitigation methodologies were deemed unsuitable due to their potential impacts, including hydromulching, straw bales, synthetic geotextile/fabric, sediment fence, re-seeding, and machine installed material such as rock channel structures. Coir logs were selected for hillslope sediment capture and erosion mitigation due to being easily carried and installed on site by hand and being a natural biodegradable material that does not carry seed or propagules like straw bales (Figure 2). The channel sediment capture structures were designed and installed using materials that could be easily carried into site on-foot, were readily available (e.g. in an emergency), would not contaminate the site (e.g. microplastics) and could withstand moderate flows (Figure 3). Overall, 250 coir logs and 13 channel sediment capture structures were installed across the site.

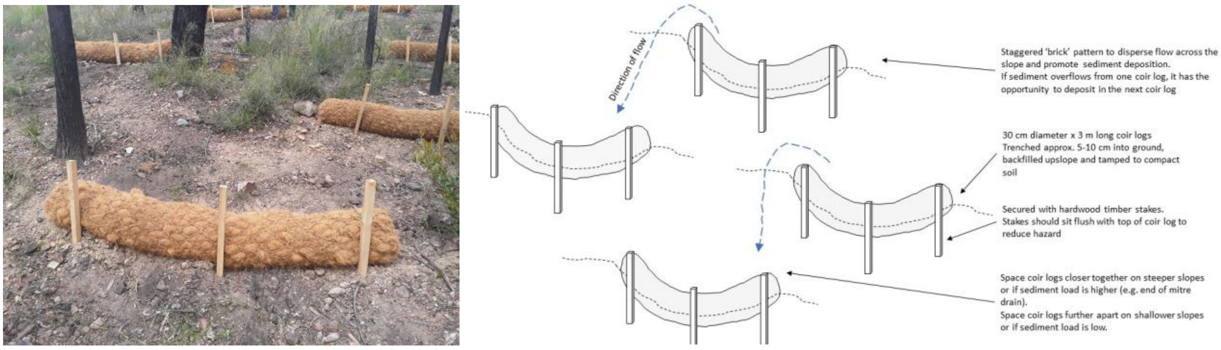


Figure 2. Example of installed coir logs.

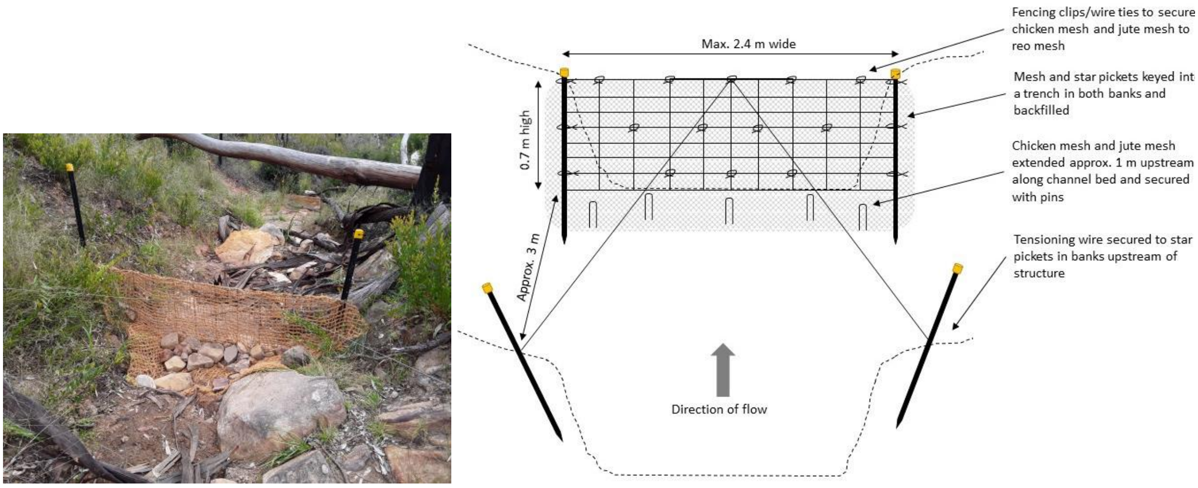


Figure 3. Example of installed channel sediment capture structures.

Monitoring

Erosion rate monitoring was undertaken using erosion pins installed across all sites to measure changes in surface levels from erosion and sediment movement. The erosion pin method was chosen due to its low disturbance of sensitive sites and suitability as vegetation cover increases post-fire compared to methods such as LiDAR, which can be hindered by the presence of dense vegetation. The hillslope erosion pins were 500 mm long, 10 mm diameter, galvanised metal rods driven vertically into the ground until only the top 100-200 mm was exposed. Pins were installed along 5 x 50 m transects and placed at 5 m intervals at each of the three sites. Transects were positioned offset from the contour of the slope to capture variations in erosion/sedimentation at different elevations across the hillslope and drainage lines. At the erosion mitigation site (Bonnum), additional erosion pins were installed behind one in five coir logs (50 pins in total). The coir log erosion pins were longer (800 mm) than the hillslope erosion pins to allow for 300 mm to be exposed above ground level to align with the top surface of the coir log (i.e. the maximum potential depth of sediment accumulation). The pins were driven into the ground directly upslope of the coir log structure, at the deepest point for sediment collection, to allow for the calculation of captured sediment volumes. The exposed length of each pin was measured using a digital depth vernier caliper to an accuracy of 0.001 mm. The difference of the exposed (above ground) length of each pin between the baseline measurement and the follow-up measurements indicated sediment loss/accumulation. For example, if a pin had 200 mm exposed in September 2021 and 220 mm exposed in May 2022, it would indicate that 20 mm of erosion had occurred at that point over 8 months.

Ten photo points were installed at each site in areas representative of site conditions and variability. The photo points were marked with 25 mm x 25 mm hardwood stakes and were revisited to collect repeat photos in four directions to record visual changes in surrounding watercourse and vegetation condition.

All sediment capture structures were assessed to monitor their performance and effectiveness. Assessment was undertaken using a survey designed to collect the following data:

- Condition - Good (fully operational), Moderate (operational, but starting to fail), Poor (partly operational, but failed in parts), Failed
- Photo of structure
- Width, length, and depth of sediment pool accumulated behind structure - Using width (a), length (h), and depth (b) measurements, the volume of the sediment pool was calculated with the equation $V=0.5*1/3\ \pi abh$

Soil and sediment samples were collected from each site and analysed for particle size, nutrient composition, and metal analytes. Samples were categorised as hillslope soil, hillslope sediment, and channel sediment. Hillslope soil samples were collected from undisturbed, unwashed soil. Hillslope sediment samples were collected from transported sediment that had accumulated naturally behind rocks or fallen logs/branches, preferably behind fallen burnt branches to analyse post-fire transported sediment. Channel sediments were collected from naturally accumulated sediment within the channel. Further sediment sampling was undertaken at 12 months post-installation to collect and analyse sediment captured behind coir logs and channel sediment structures installed at Bonnum.

Visual indicators of watercourse condition and change were identified in the field and recorded. These features included:

- Bed and bank stability (extent and severity of erosion, evidence of slumping)
- Riparian vegetation associations and vegetation condition
- Geomorphic features such as bars, benches, and pools
- Evidence of channel adjustment including migration, expansion, and incision
- Evidence of excessive sedimentation

Vegetation monitoring was conducted by an ecology consultant and involved a total of 32 fixed 20 m by 20 m plots established across the Bonnum, Brimstone, and Pearce’s Mountain sites. Vegetation structure, composition, and function data was collected and monitored over time. The methodology applied at each monitoring plot was based on a modified Biodiversity Assessment Method (BAM) plot technique, allowing a robust and repeatable field methodology (Department of Planning, Industry and Environment, 2020).

Results

The recovery timeframe and trajectory of this project needs to be considered in the context of the several wet years and cool summers that have occurred since the Black Summer bushfires in 2019/20. It is likely that the initial erosion would not have been as severe if a major rainfall event did not immediately follow the fires. However, it is also likely that the vegetation recovery would not have been as successful if there was low rainfall and extreme summer temperatures. Rainfall recorded at High Range (Gauge 68262) during the monitoring period was 1759.6 mm, including a major rainfall event of 364.4 mm (21 February-9 March 2022), which exceeded the 350.8 mm of the 6-19 February 2020 post-fire event.

The overall observed recovery timeline at all three sites included:

- 3 months post-fire (May 2020) – limited evidence of vegetation recovery, no ground cover/leaf litter, substantial areas of bare earth (Figure 4-B)
- 5 months post fire (July 2020) – localised vegetation recovery of select species, no ground cover/leaf litter, substantial areas of bare earth
- 9 months post fire (November 2020) – localised vegetation recovery of a wider selection of species including substantial epicormic regrowth, establishing ground cover/leaf litter from leaf and bark fall, localised areas of bare earth
- 1.5 years post fire (August 2021) – substantial regrowth of ground and mid-storey species, established ground cover/leaf litter, bare earth still evident in areas identified at 9 months post-fire.
- 2.5 years post fire (October-November 2022) – dense regrowth of ground and mid-storey species, re-establishing canopy cover, dense ground cover/leaf litter, bare earth still evident in areas identified at 9 months post-fire (Figure 4-C).

Geomorphic/Landscape recovery

All sites experienced riparian and channel vegetation regeneration leading to soil formation and stabilisation of channel sediment deposits resulting in channel contraction. Despite complete stripping of watercourse beds and banks following the Black Summer bushfires, watercourses are recovering towards pre-fire conditions and did not continue a trajectory of instability. Erosion pin measurements confirmed that on average all sites were accreting soil/ground cover and not continuing to erode.

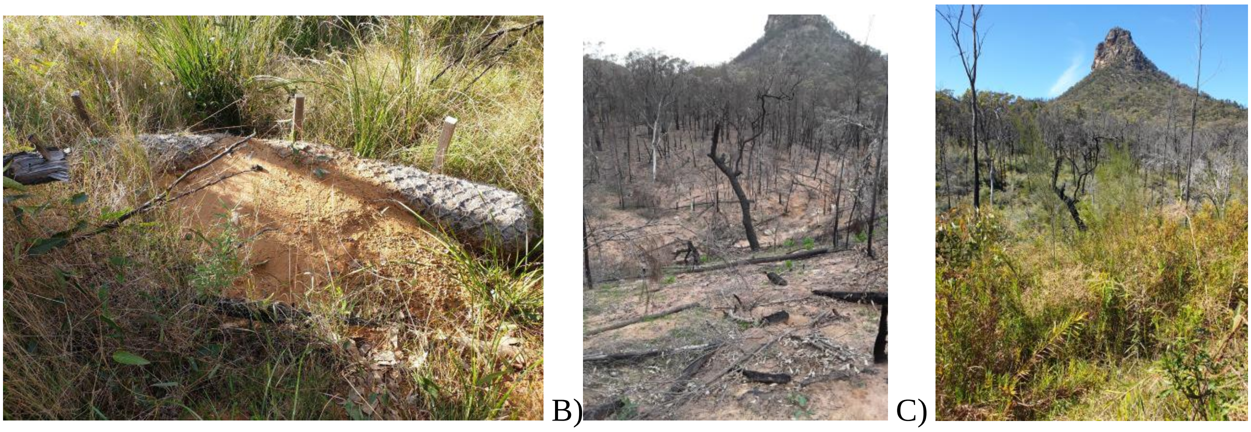
Channel structures

The channel structures were an effective method of capturing sediment (approx. 4.7 T) and withstood bankfull flow conditions (approx. 1-1.5 m deep x 2-2.5 m wide) without failure. The combination of reinforcement mesh, chicken wire and jute mesh across the structure was very effective at pooling water upstream of the structure to promote sediment deposition. The vertical mesh panel became blanketed in fine sediment and leaf litter that reduced the permeability of the mesh and improved its water holding ability. Minor erosion occurred immediately downstream of the structures, however the erosion did not compromise the effectiveness of the structures or exceed the volume of sediment captured by the structures.

The channel structure design was effective for single spans across channels up to 2.5 m wide where bedrock beds or boulder beds inhibit additional mid-channel star pickets. If channels have a sediment bed that allows for additional mid-stream star pickets for reinforcing the structure, then wider spans could be achieved. The channel structures require channel banks that are higher than the structure (i.e. 0.7 m high) to allow for it to be keyed into the banks. The channel structures withstood the flow from a relatively steep catchment with an area of approx. 9.5 ha and channel gradient of approx. 14%. It is assumed that a catchment up to this size and gradient would be suitable for this structure design. Due to the structures withstanding overbank flows, they could be suitable for larger catchment with lower channel gradients (i.e. higher discharge but lower flow velocity). It is recommended that the positioning of channel structures is assessed by an experienced professional with knowledge of watercourse character and behaviour to prevent adverse impacts from structures. The channel structures are expected to have a lifespan of over 20 years. However, the captured sediment is becoming recolonised by in-channel vegetation which will take over the role of long-term stabilisation prior to the structure’s design lifespan.

Hillslope structures

Coir logs were effective for capturing hillslope sediment (6.5 T), particularly from concentrated sources such as fire trail drains (Figure 4-A). The staggered coir log pattern with a concentrated array of multiple coir logs was effective at capturing sediment and dispersing overland flow to prevent rilling. Sediment captured behind coir logs provided a stable area for vegetation to establish, particularly in steeper areas of bare rilled earth. Coir log placement should be concentrated below fire trail drains, natural areas of concentrated flow (rills), and across bare areas of stripped soil. However, they should not be placed in established drainage lines (e.g. gullies, creeks, etc.) with entrenched channels, as they will not withstand the flow conditions. Coir logs remained effective over 12 months post-installation and the majority remained effective despite moderate animal disturbance. The coir logs have an expected lifespan up to 2 years: however, the vegetation colonising the captured sediment will take over the role of long-term stabilisation prior to the coir logs decomposing. No substantial adverse impacts were recorded from the coir log installation.



A) B) C)

Figure 4. A) Sediment captured behind hillslope structure. B) Bonnum site post-fire (May 2020). C) Bonnum site post-works (November 2022)

Sediment characteristics

The captured sediment had lower concentrations of fine particles, nutrients and metals compared to the surrounding natural soil. The sediment characteristics suggest that coarser sediment has a greater chance to settle out of suspension behind the structures whilst the fine grain sediment, nutrients and metals remain in suspension and travel further downstream. Longer settling time would be required to retain fine sediment, nutrients, and metals. However, this would require large holding basins which would be difficult to achieve on steep terrain without installing taller structures. Taller structures would generate higher velocity flows and have greater downstream impacts from overtopping flows unless the overflow channel was armoured. The access and terrain required for a settling basin sufficient for the capture of fine sediment is not present in the Warragamba Catchment and a structure of this nature is not achievable in a rapid post-fire response context.

On-going Monitoring

The results of this monitoring program suggest that all sites are stabilising and there are reduced rates of erosion/sediment movement across the sites. It can be assumed that this trend will continue and there is no need for on-going detailed erosion/sediment capture monitoring. It is recommended that the coir log and channel structures are visually inspected annually to determine their longevity and performance. Visual inspections with comparison to previous photos will determine trends in vegetation establishment surrounding the structures, any major re-working of captured sediment and changes in watercourse condition. The hillslope and coir log erosion pins have been left in-situ at all sites. This provides the opportunity for long-term monitoring if another bushfire/flood event occurs. The November 2022 measurements from this study can provide a baseline for comparison to any future post-fire monitoring.

Key learnings and recommendations

Erosion Mitigation Works - Planning

Decision Points

The following decision points should be considered when determining if post-fire erosion mitigation works should be pursued:

- The natural vegetation regeneration potential of an area must be considered. If there is evidence of ground cover vegetation establishment at the time of inspection, then it is likely that the benefit of undisturbed vegetation establishment will outweigh the benefit of intervention.

- Erosion mitigation works require an accessible location either from road or helicopter and the ability to establish a worker's camp or have workers travel to accommodation. This criterion excludes a large portion of the Warragamba catchment, which is too remote.
- The method applied in this project could be scaled to treat a larger area but is limited to the availability of materials, transport of materials, the availability of labor and the impact of site disturbance over an extended installation period. A realistic limit to this method would be 4-5 times the scale of this project.
- The erosion mitigation method needs to effectively capture the substances risking raw water quality (i.e. fine sediments, metals, etc.) rather than low risk substances (i.e. boulders, coarse sand, etc.)

The majority of the Warragamba Catchment is not conducive to post-fire erosion mitigation works due to the terrain, remoteness, and limited access. The Warragamba Catchment cannot be directly compared to other major drinking water catchments in Australia and the post-fire response cannot be the same. Most other drinking water catchments in Australia have terrain and landscape features that allow for erosion mitigation works to be more readily implemented and are not constrained by the same conditions as the Warragamba Catchment.

Materials

Planning the type and availability of materials to be used is essential, particularly in a post-fire/emergency context. The channel structures were designed to utilise readily available materials to prevent extended lead times for sourcing specialised materials. The availability of specialised erosion control materials such as coir logs was limited due to the widespread erosion control response required following the Black Summer bushfires. All suppliers along the east coast of Australia sold out of coir logs and jute mesh following the Black Summer event and did not regain stock for approx. 3 months when overseas supply was sourced. If specialised materials such as coir logs are required for rapid post-fire response, then a stockpile of supplies should be kept to prevent delay from supply shortages. It is recommended that a minimum of 250 coir logs and 750 hardwood stakes are stockpiled (approx. 16 pallets, or approx. 25 m^2) to allow rapid deployment of erosion mitigation structures across 10 ha. These materials must be stored in dry conditions to prevent decay.

Project management

A low ratio of skilled labour vs. general labour was critically important when implementing the project. A ratio of approx. 1 skilled labourer to 3 general labourers ensured works were implemented efficiently and to the required quality. It was observed that larger unsupervised teams of unskilled labourers would frequently 'drift' from the required quality of works without on-going supervision and quality control. Safety must be prioritised for all projects; it was particularly critical due to the remote site and use of unskilled general labour. All labourers must be instructed on the correct installation of erosion mitigation structures. It is suggested that the method is explained and demonstrated by experienced field staff, then trialled by the general labourers, reviewed, and corrected as needed prior to broad scale implementation.

Erosion Mitigation Works – Installation

Access

Transport of materials into remote catchment areas must be considered when planning post-fire erosion mitigation works. The Bonnum Pic site was a relatively close site to access (1.5 hours from Mittagong) compared to many areas of the Warragamba Catchment. If sites have further round-trip distances or are limited to smaller vehicle access (<7T), then time allowances for material transport would be considerably more or it may warrant the use of helicopter delivery.

On-foot site access for distributing and installing the coir logs/channel structures resulted in the establishment of trampled tracks, which remained evident in on-going monitoring. Many of the tracks followed existing animal tracks; however, the repetitive use of any tracks should be avoided to allow effective vegetation regeneration. The maximum on-foot distance from the road/stockpiles was approx. 120 m and did not significantly inhibit effective distribution of materials, staff readily accessing supplies (e.g. food, water or shelter), supervision of staff, or communication with staff. If the installation site is >200 m from the road or stockpiles, then it is recommended that materials (e.g. pallets of coir logs) are helicoptered to distributed stockpiles amongst the installation area to speed up the installation process and minimise trampling tracks.

Monitoring

The majority of post-fire soil loss occurred immediately following the Black Summer bushfires. For future events, it is considered essential that any erosion mitigation works are installed within 3 months post-fire and prior to the first major rainfall event. If post-fire erosion mitigation works are not completed within 3 months, or prior to the first major rainfall, the works should be targeted to areas with no evidence of vegetation regeneration (i.e. bare soils) and areas with evidence of regrowth should not be disturbed.

The 'Do Nothing Approach'

This study identified that in many circumstances the 'do nothing approach' can provide the same outcome as intervening. Monitoring of the control sites (Pearce's Mountain and Brimstone) and intervention site (Bonnum) revealed that despite all sites initially being absent of vegetation and experiencing soil loss in the initial post-fire rainfall event, all sites were well vegetated and had a reduced erosion rate 2.5 years post-fire regardless of intervention or not. However, areas that were bare 9 months post-fire remained absent of vegetation long-term and could be an effective way of targeting intervention efforts. If erosion mitigation works were implemented across all sites, it is likely that the impact of the intervention (e.g. soil compaction, vegetation trampling, etc.) would have outweighed the expected benefit. As such, the natural recovery potential of areas (particularly sensitive areas such as Declared Wilderness) should be considered when planning if a post-fire response is required.

Conclusions

Overall, the post-fire erosion mitigation project met the objectives established for the planning, implementation, and monitoring components of the project. Project planning effectively met safety and environmental requirements for implementing the work, including landowner environment and heritage approval. All works were installed as planned and without safety or environmental incident.

The erosion mitigation works resulted in moderate sediment capture results; however, it is assumed that the volume of sediment capture would increase exponentially the sooner the works are completed following the bushfire event. Further, greater erosion mitigation outcomes would be expected if the works are completed prior to any post-fire rain events. The erosion mitigation methods successfully captured sediment, which was a key priority for protecting raw water quality in the drinking water catchment. The structures withstood several intensive rainfall events without failure and were a low impact option without adverse environmental effects. The monitoring methods successfully tracked site recovery without invasive monitoring methods or adverse environmental effects.

Acknowledgments

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