Post-fire response in the Warragamba drinking water catchment

Rebecca Mabbott[1], Rhiannon Hughes[2]

1 Soil Conservation Service, 4PSQ, 12 Darcy Street, Parramatta NSW 2150. Email: rebecca.mabbott@scs.nsw.gov.au
2 Soil Conservation Service, 4PSQ, 12 Darcy Street, Parramatta NSW 2150. Email: rhiannon.hughes@scs.nsw.gov.au

Key Points

- The 2019/2020 wildfire season resulted in over 300,000 hectares of bushland being burnt in the Warragamba drinking water catchment.
- WaterNSW was concerned about impacts on raw water supply and required a catchment assessment to identify potential on-going risks to the catchment and raw water quality.
- Desktop assessment identified potential high raw water quality risk areas at 17 locations within a 15 km radius of Lake Burragorang.
- Erosion mitigation works were recommended at 11 locations where severely burnt vegetation showed delayed natural vegetation recovery.
- Warragamba Catchment has limited potential for erosion mitigation interventions due to its steep and dissected landscape with high energy, confined watercourses.

Abstract

The Warragamba Catchment, responsible for 80 per cent of Sydney's drinking water supply, had 320,000 ha of land impacted by the 2019/2020 Black Summer bushfires. This scale of impact in a drinking water catchment was unprecedented in Australia. In response, the Soil Conservation Service (SCS) was engaged by WaterNSW to investigate the severity of damage to the catchment, risk to raw water supply and feasibility of mitigating risk to raw water quality using erosion control methods. SCS integrated analysis of fire extent and severity model (FESM), erosion risk models, River Styles data, proximity to water storage/offtake, distribution of vegetation buffers and on-ground inspection to identify areas posing the highest risk to raw water supply from sediment and greatest feasibility for on-ground erosion mitigation works. SCS conducted a literature review to determine the most suitable on-ground erosion mitigation methods for the wilderness and world heritage area. The project provided greater insight into the preparedness of industries to bushfire response, the feasibility of intervening in post-fire recovery at large scales, particularly in National Park reserves, wilderness and world heritage areas, and knowledge gaps in post-fire catchment response. This investigation will inform future bushfire response in water supply catchments. SCS's review of current post-fire erosion control methods has identified where efficiencies can be gained and numerous knowledge gaps on the suitability and environmental impact of post-fire erosion control methods being used in Australia.

Keywords

bushfire recovery, erosion risk, water supply, erosion control

Introduction

Erosion rates and sediment sources can be significantly altered post-fire, resulting in changes to landforms, watercourse conditions and water quality (Dunkerley, et al., 2009). Fire can cause an acceleration of existing erosional processes such as gullying, watercourse expansion and hillslope erosion due to the removal of ground and canopy cover and increased rainfall runoff (Wilkinson, et al., 2009; Dunkerley, et al., 2009). Increased erosion rates and changed sediment sources can result in reduced water quality, including elevated turbidity and increased dissolved constituents such as nutrients (Lane, et al., 2008; Wilkinson, et al., 2009) and heavy metals (White, et al., 2006; Smith, et al., 2011). Raw water quality impacts can be experienced for many years (2-5 years) post-fire due to increased water yields from lower vegetation cover (Smith, et al., 2011). Increased water yields post-fire can affect raw water quality by either diluting constituents that are typically supply limited or increasing total loads of constituents that have unlimited supply and are typically transport limited (White, et al., 2006). Elevated turbidity can threaten raw water quality and treatment due to hindering detection of bacteria and viruses, promoting bacterial growth from elevated levels of adsorbed nutrients and limit the effectiveness of disinfections (NHMRC, 2004). Fire severity is one of the most influential factors on post-fire erosion rates due to the severity of vegetation removal (Dragovich & Morris, 2002; Morris, et al., 2014; Benavides-Solorio & MacDonald, 2005). High burn severity has a greater likelihood of causing increased post-fire erosion due to the removal of ground cover vegetation, whereas low burn severity or unburnt areas have been observed to aid in the reduction of runoff and sediment transport from more intensely burnt areas (Cawson, et al., 2011; Morris, et al., 2014).

The Warragamba Catchment was extensively burnt during the 2019/2020 bushfire season by bushfires that occurred between late November 2019 and mid-February 2020. Approximately 320,000 ha of bushland was burnt by the Erskine Creek, Green Wattle Creek and Ruined Castle Fires in the Warragamba Catchment (affecting approximately ~80% of the protected forested areas surrounding Lake Burragorang, representing ~30% of the entire catchment). The fires were shortly followed by a widespread storm event from 7 to 10 February 2020 with approximately 400-500 mm of rain recorded over a 4 day period within the catchment. These combined events posed a post-fire raw water contamination risk to Lake Burragorang (Warragamba Dam).

To address the potential post-fire raw water contamination risk, silt curtains and booms were deployed by WaterNSW at key inflows of Lake Burragorang and near the offtake at Warragamba Dam to mitigate the inflow of ash to the system in the event of significant rainfall. An incident managing team was put in place and extensive monitoring of incoming water quality was undertaken. By implementing operational strategies, including source blending and offtake depth selection, adequate raw water supply was maintained to Sydney Water's filtration plants with no interruption to supply of safe drinking water to Greater Sydney customers. A specialist team of WaterNSW experts were also assembled to understand the potential longer-term consequences of significant bushfire damage in the catchment on raw water quality. As part of WaterNSW post-fire response, the NSW Soil Conservation Service (SCS) was engaged to identify where erosion and sedimentation pose an on-going risk to raw water quality and to locate, design and cost the implementation of erosion control mitigation works to further limit the short-term delivery of eroded material and contaminants into Lake Burragorang. SCS provided recommendations for improving future post-fire response in drinking water supply catchments.

Study Area

The Warragamba catchment covers an area of 9,050 km^2, spanning from Tarago to Lithgow. The catchment is the largest of Sydney's drinking water catchments and is responsible for 80 per cent of Sydney's drinking water supply. The predominant land uses in the catchment are livestock and grazing in the south (35 per cent, ~600,000 ha) and nature conservation in the north (28 per cent, ~485,000 ha). Other significant land uses include minimal land use, forestry, rural and urban residential areas, horticulture, cropping, mining and quarrying. The vegetation of the catchment is mostly cleared with the remaining extant vegetation situated in nature reserves such as Blue Mountains, Kanangra-Boyd, and Nattai National Parks, Yerranderie State Conservation Area and the Burragorang State Conservation Area. The area immediately surrounding Lake Burragorang (and other dams in the drinking water catchment) is declared Special Area. These Special Areas have restricted or prohibited access, protect vegetation and ecological values and act as a buffer to protect water quality. The Warragamba Special Area is characterised by extremely high levels of biodiversity, however, over 37 per cent of the area is classified as moderately to highly disturbed (NPWS, 2003). Some of this area is also mapped as Declared Wilderness under the *NSW Wilderness Act 1987* and the Greater Blue Mountains Area under *The World Heritage Convention.*

Prior to the 2019/2020 bushfire event, Level 2 Water Restrictions were in place in the Greater Sydney and Blue Mountains area with Warragamba Dam at 42 per cent storage capacity. From 7 to 10 February 2020, the Warragamba Catchment experienced a widespread storm event with approximately 399 mm and 517.4 mm of rain recorded over a four-day period at the Warragamba (Warragamba Dam wall) and Katoomba (Farrells Road) weather stations, respectively. As a result, Warragamba Dam increased to 70 per cent storage capacity in less than a week.

Methods

Desktop assessment

A pilot desktop assessment was undertaken to identify potential locations where erosion and sedimentation pose an on-going risk to raw water quality and to locate potential sites for the implementation of erosion control interventions to limit the further input of eroded material and contaminants into the water storage. The investigation was constrained to the sub-catchments of Lake Burragorang affected by the 2019/2020 bushfire season, or sub-catchments immediately above affected areas. Lake Burragorang sub-catchments excluded from the investigation included Upper Wollondilly, Mid Wollondilly, Mulwaree, Wingecarribee, Upper Coxs and Mid

Coxs. Within the study area, a focus was placed on sub-catchments immediately connected to Lake Burragorang due to their increased potential to effect raw water quality in the short-term (3-5 years). SCS integrated analysis of datasets including fire extent and severity model (FESM), erosion risk models, River Styles, access road/fire trail network, proximity to water storage/offtake and distribution of vegetation buffers to identify areas posing the highest risk to raw water supply from sediment and greatest feasibility for on-ground erosion mitigation works. FESM (DPIE, 2020) describes the area affected by fire through a standardised classification of 'fire severity'. The FESM dataset was used over the Google Earth Engine Burnt Area Map (GEEBAM) (DPIE, 2020) as it uses a combination of field data and satellite imagery resulting in a more precise estimate of fire extent and fire impacts. Fire severity was classified as unburnt surface with green canopy (unburnt), burnt surface with unburnt canopy (low), partial canopy scorch (moderate), full canopy scorch (+/-) partial canopy consumption (high) and full canopy consumption (severe). Estimated erosion rate dataset provided by Yang, 2020 was classified into four erosion risk classes (<=2, 2-10, 10-20 and >20 t/ha/month), see Yang et al. 2018 for model methodology. River Styles (Fryirs & Brierley, 2005) were used as an indicator of the distribution and transport of sediment within the catchment and which watercourses were likely to release sediment (source), convey sediment (transfer) and capture sediment (storage) surrounding the water storage. Watercourse categorisation was sourced from the River Styles Spatial Layer for New South Wales (NSW Office of Water, 2012). Proximity to water storage/offtake was calculated by applying buffers around the perimeter of Lake Burragorang (measured as full capacity) at 1 km and 5 km intervals. Distance from the perimeter was used as a substitution for stream distance. Distance from the drinking water extraction point at the Warragamba Dam wall was measure along the length of Lake Burragorang. Catchment areas that were not burnt or had low burn severity during the 2019-20 wildfire season were considered for their role in trapping sediment within the landscape. As described by Cawson et al. (2011), intact vegetation situated downslope or downstream of moderately or severely burnt areas can effectively trap sediment and prevent sediment transport into watercourses and further downstream. Potential vegetation buffer areas were considered those classed as 'Unburnt Surface with Green Canopy' or 'Burnt Surface with Unburnt Canopy' in the FESM dataset (DPIE, 2020). Potential vegetation buffer areas were visually compared to high erosion risk areas to determine if potential sediment yields could be captured by downslope or downstream vegetated areas.

Spatial analysis was undertaken to identify watercourses that intersect with fire trails to determine watercourse locations that could be easily accessed by vehicle. High erosion risk sites for each catchment, context and additional watercourse-trail intersections were chosen for field inspection to maximise the number of sites inspected during the field work campaign.

Field Assessment

High erosion risk sites identified in the desktop assessment and categorised as potential catchment intervention or monitoring locations were included in the field inspection plan for three days of vehicle-based and two days of boat-based inspection. SCS undertook a field assessment and inspection of the Warragamba Catchment from

11 to 15 May 2020. The objectives of this investigation were to gain an understanding of the catchment condition and response following the recent bushfire and storm events that occurred in 2019/2020. The selected field inspection sites were prioritised to ensure a range of different catchment contexts, landscape positions and burn severities, to build an understanding of broader catchment condition and processes. Observations from inspected sites were then extrapolated to areas of similar contexts in inaccessible areas of the catchment. SCS inspected potential intervention sites and proposed on-ground works where there was evidence of continued high erosion risk and/or no short-term vegetation recovery. Modelling and datasets prepared during the desktop assessment were compared to on-ground conditions and ground truthed. The suitability of sites for short or long-term monitoring was determined.

Methods used to determine the impact of the recent bushfire and storm events and the rate of recovery were observational and qualitative, except where direct measurements of erosional or depositional structures could be made. Observational methods included identifying the depth of freshly exposed, unweathered and unburnt rock or timber surfaces indicative of the depth of hillslope and in-channel erosion post-fire; the depth of freshly deposited hillslope and in-channel sediment to identify the extent of upslope/upstream erosion and areas that are likely to be on-going sediment sinks within the catchment; groundcover extent and composition, including recovering vegetation, leaf litter or rock armouring, to determine the resilience of surfaces to ongoing rain splash and surface wash erosional processes; the presence/absence, composition, texture and volume of sediment deposits in channels and on floodplains to determine the characteristics of sediment that remains within watercourses or has been transferred to lower sediment storages or water bodies. These observations used the assumption that during the waning phase of a high flow event course sediment will be deposited preferentially to fine grained sediment. Density and form of regrowing vegetation and the presence of fast colonising species and groundcovers, such as grasses, that will contribute to sediment capture and erosion mitigation. Presence/absence of unburnt vegetation buffers downstream of severely burnt areas that could contribute to sediment capture. Position of organic debris deposits on banks and floodplains as an indicator of peak flood height. Density of remaining canopy cover and potential to provide additional leaf litter for groundcover erosion control.

Results

Desktop Assessment

The desktop assessment identified 17 locations within the study extent that had the potential to pose a risk to raw water quality. It further recommended field assessment and inspection should be undertaken to draw conclusions about the modelled erosion risk, identify stages of recovery and justify the need for intervention in the remote areas of Warragamba Catchment.

Field Assessment

Not all locations recommended in the desktop assessment were accessible during the field inspection, however SCS inspected a total of 32 sites that were considered to be representative of the differing context of the catchment. SCS recommended catchment interventions could be undertaken at 11 sites where severely burnt vegetation showed delayed natural vegetation recovery to promote sediment capture.

Key findings and outcomes of the field assessment included that it is likely the February 2020 storm event mobilised a large proportion of the immediately available sediment within the catchment. Substantial geomorphic activity occurred following the fire and storm events, as evidenced by in-channel erosion and sedimentation, isolated debris flow deposits and hillslope erosional processes such as rill and inter-rill erosion. Sediment that did not enter Lake Burragorang was potentially being stored within watercourses as in-stream sediment deposits (sediment slugs) that are likely to be remobilised in future events and may cause a future impact on raw water quality. The majority of the Warragamba Catchment is mapped as low to high burn severity and is showing good signs of natural vegetation recovery and soil surface stabilisation. Areas mapped as moderate to severe burn severity were the most likely to have high on-ground erosion risk. Severely burnt areas showed delayed or limited regrowth and were at high risk of ongoing hillslope and channel erosion if high intensity rainfall events occur before natural vegetation recovery and soil stabilisation occurred. Isolated pockets of low or unburnt vegetation were distributed throughout the catchment and have the potential to act as a buffer to sediment transport. Access tracks and containment lines should be repaired and stabilised to mitigate potential increased sediment delivery to the catchment. Warragamba Catchment has limited potential for erosion mitigation interventions due to its steep and dissected landscape with high energy, confined watercourses.

Additional Recommendations

Monitoring programs should be established within the Warragamba Catchment to track post-fire impacts/recovery to inform the current post-fire response and guide future disaster management and planning. Water Authorities should undertake a cost-benefit analysis of raw water quality management options to compare on-ground erosion mitigation works against other water treatment alternatives especially in large scale catchments. Fire and management trail networks should be repaired and maintained to best practice standards to reduce background sediment transport rates. WaterNSW should investigate options to expediate the environmental approval process for post-fire catchment erosion control works in sensitive ecological environments. Learnings from this investigation should be integrated into future bushfire recovery planning for NSW drinking water supply catchments.

Discussion

Catchment observations and sediment control feasibility

Most of the Warragamba catchment was not severely burnt and displayed good signs of natural recovery with groundcover vegetation rapidly recovering post-fire. Recommended intervention sites would treat a very small proportion of the catchment area due to being focused at severely burnt areas that are showing delayed natural recovery (vegetation regrowth).

The catchment of Lake Burragorang is composed of mostly steep, bedrock confined, high energy streams that have limited potential for intervention. These high energy streams have restricted capacity for the storage of sediment due to their lateral confinement and high flow velocities. Most sediment that could be captured within these watercourses by large interventions, for example debris flow capture devices, is above the sediment fraction that is of most concern to WaterNSW (silt and clay). The majority of finer sediment (silt and clay) would be transported further downstream as suspended load (Nyman, et al., 2020). Nyman et al. (2020) identified that in deposited debris flow material only 11 per cent of eroded fines (< 63 µm) were deposited and the remaining clay and silt load was preferentially transported downstream. Any intervention in high energy streams capable of capturing fine sediment would likely only withstand low flow conditions and would re-release captured sediment during larger events, potentially creating a greater spike in sediment delivery to the dam. Because of these reasons, it was not recommended treatment activities within these high energy systems.

In response, SCS recommended that if catchment intervention is pursued, sediment should be captured before it enters high energy streams to promote the long-term storage of finer fraction sediments. This approach requires the installation of sediment capture devices on hillslopes and low order watercourses in areas subject to on-going surface erosion, notably severely burnt headwaters. Sediment control devices suitable for headwater streams, such as channel checks, are likely to be more effective at capturing sediment in the short-term due to being engaged by more frequent low magnitude rainfall events (<10 year ARI) as well as high flow events (10 year ARI). Comparatively, large-scale interventions targeted at events such as debris flows, are likely only to be engaged under high magnitude events and may not be engaged for many years at a time.

Modelling accuracy

The preliminary erosion risk model prepared by Yang (2020) for the Warragamba catchment had not been ground truthed or validated in the field to test its performance at the time of this investigation. The model was produced using fractional vegetation cover indices derived from MODIS datasets which have a large pixel size (500 m). Yang, et al. (2018) found MODIS to be inadequate for estimating post-fire ground cover in the Warrumbungle National Park due to the complex terrain and heterogenetic ground cover types. Similarly, SCS identified that the model required further refining to better represent on-ground conditions in the Warragamba Catchment. Due to slope being used as a parameter for determining estimated erosion rate it was been identified that there could be false emphasis on the risk of escarpment areas due to their near vertical slopes. These areas were cross referenced with the FESM data for confirmation of the impact to areas and the FESM burn severity was identified as being more closely related to on-ground erosion risk than the Yang (2020) model. There is potential erosion risk in less steep, but severely burnt areas and the estimated erosion model may need to be adjusted after being ground truthed for the Warragamba catchment, particularly if high rates of erosion are observed in lower relief areas. As such, analysis using this dataset should be considered as an indication of the areas that may be at risk of further erosion. Initiating widescale catchment interventions based on this preliminary dataset could be problematic and should be ground truthed in the field for validation prior to undertaking interventions. Updating the estimated monthly hillslope erosion model using finer scale satellite imagery would provide a better indication of areas that have the potential to impact raw water quality in the future.

Organisational preparedness

The project provided greater insight into the preparedness of industries to bushfire response, the feasibility of intervening in post-fire recovery at large scales, particularly in wilderness and world heritage areas, and knowledge gaps in post-fire catchment response. This investigation will inform future bushfire response in water supply catchments.

Conclusions

Following the bushfire season, a high intensity rainfall event occurred at the beginning of February 2020 with increased rates of sediment, ash and debris delivered to Lake Burragorang. Raw water quality impacts were recorded and observed throughout lake Burragorang. WaterNSW engaged SCS to identify where erosion and sedimentation pose an on-going risk to raw water quality and to locate, design and cost the implementation of erosion control mitigation works to further limit the short-term delivery of eroded material and contaminants into Lake Burragorang. The desktop assessment identified 17 locations within the study extent that have the potential to pose a high risk to raw water quality. A catchment inspection of the key locations was undertaken via vehicle and boat to draw conclusions about the modelled erosion risk, identify stages of recovery and justify the need for erosion mitigation works. On-ground erosion control works were recommended at 11 sites. Overall, the inspection suggested the catchment recovered well following the 2019/2020 bushfire and storm event with a good coverage of groundcover and vegetation regrowth at the majority of inspected sites. Sites mapped as severe burn severity showed limited regrowth, large areas of absent vegetation and exposed soil/sediment. Substantial geomorphic change was observed in most sub-catchments, however, sediment deposits were largely composed of sand and coarser fraction particles. Limited finer fraction sediments were observed, suggesting there is limited opportunity to capture finer grained material once it has entered tributaries and before it enters Lake Burragorang. Overall, catchment observations suggest erosion control mitigation works should look to stabilise finer fraction sediments at the source (hillslopes and upper tributaries) rather than targeting larger scale processes such as debris flows and high energy streams.

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