Bushfires and the Risks to Drinking Water Quality

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Introduction

Bushfires in drinking water catchments can directly compromise water quality in the short term and more broadly in the long term. For months and years afterwards, it changes the water balance and catchment landscape. During active fires, forest litter is replaced by an ash and a charcoal layer with ash settling on lakes and reservoirs. Rainfall events post-fire can have a significant effect on water quality; from increased rates of erosion, increased sediments and turbidity and the introduction of a range of chemicals and precursors into the water supply.

The degree in which a bushfire has negative impacts on water quality depends on multiple factors; such as intensity of the fire, post-fire precipitation, catchment topology and local ecology.

This factsheet highlights the priority issues for concern, along with secondary issues that have been seen to arise across Australia and internationally.

Burn Intensity

The intensity of a bushfire is a key determinant of the severity of the water quality consequences. Low intensity fires that do not burn the crown of the forest lead to increased leaf litter. Therefore, during post-fire rainfall, leads to increased dissolved organic carbon (DOC) concentrations in water storages. If the leaf litter ends up in streams, this can result in an increase in microbial activity, reduced dissolved oxygen levels and release of metals from the sediments - particularly manganese.

High intensity fires, which burn the above ground matter and soils, can result in a different range of issues. Due to the high heat generated by these fires, most of the organic matter is volatilised resulting in the inorganic nutrients in the leaves leaching out and passing into the soil. As a result, following rainfall, there will be an increase in phosphorus and nitrogen entering waterways and reservoirs. The increase in phosphorous can lead to future algal blooms. High intensity fires can also lead to leaching of trace elements, such as copper, lead and chromium. In particular, the volatilisation of mercury, which can reabsorb and be released as methyl-mercury.

High intensity fires can result in the loss of riparian vegetation that support the banks of rivers and streams. With the loss of these trees and their root systems. Over time this can result in land disturbance and erosion causing an influx of sediments, nutrients, ash and burnt organic material into raw water supplies.

High intensity burns not only have a water quality impact but can have a water quantity impact; leading to an increase in water yields from the catchment by a combination of hydrologic processes. This can include dramatic decreases of evaporative losses (interception of precipitation and transpiration) from the forest canopy, increases in soil moisture and runoff generation from hillslopes. These in turn, can produce greater storm runoff. Including large peak flows and increase overall water production from fire affected landscapes.

Suggested Priorities

Depending on the severity of the fires, there can be different water quality risks. For low intensity fires water quality managers should be particularly concerned with:

- increases in DOC; and
- increases in dissolved metals from sediments such as iron and manganese.

For high intensity burns water quality managers should be particularly concerned with:

- increases in suspended solids and turbidity from ash and soil;
- increase in inorganic nutrients, particularly phosphorous, leading to cyanobacteria; and
- potential increase in trace metals.

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Based on previous bushfire experiences in Australia and across the globe, water quality issues have been divided into two main categories: Priority 1 and Priority 2. Priority 1 covers the most commonly reported issues from bushfires that can cause significant water quality concerns and disruption to supply. Priority 2 includes issues that have occurred at lesser frequencies or the consequences are considered less severe.

Priority 1

Suspended Solids

Suspended solids input into waterways, following fires and rain events, lead to step change increases in turbidity and colour of the water; while also transporting other particle-associated contaminants. The magnitude of impacts from suspended solids entering waterways is highly variable and dependant on the intensity, magnitude and frequency of rainfall events. Following bushfires, a range of factors can influence post-fire erosion. It has been reported that up to 500 times the background sediment loads have occurred following fires and associated rainfall. Most of this was attributed to channel erosion and incision of the unchanneled drainage lines - following short duration high intensity summer storms. An example is after the Cotter fire in Canberra in 2003 where 482 Km^2 of the catchment burned, the maximum turbidity was 30 times higher than the previous maximum. It can take up to two years for reservoirs to return to pre-fire conditions. However, in other cases, some reservoirs were not significantly impacted following large fires and associated rainfall. This can be due to the capacity of the reservoir to mitigate the impacts from the contaminated inflows.

Organic Carbon

Fires can have a major impact to organic matter on forest floors and in surface soils. Through runoff and erosion, the carbon can be exported into waterways. Increases in carbon and DOC, whilst not itself a major concern, is a precursor to disinfection by-products (DBPs), such as trihalomethanes (THMs), haloacetic acids (HAAs). With an associated increase in forms of nitrogen following fires, nitrogenated DBPs can also form, such as haloacetonitriles (HAN) and halonitromethanes. Any impact is difficult to predict since the formation of DBPs is dependent on carbon speciation, background levels of DOC and water treatment processes. Of more immediate concern is that a change in the levels and speciation of DOC in raw water, can have an impact on water treatment process; requiring optimisation of coagulants to remove higher/different organic fractions from water.

Nutrients

The impacts from nutrients, particularly nitrogen and phosphorus, can be a major issue associated with bushfires in drinking water catchments. Some studies have shown more than an order magnitude increase in background concentrations after fires; while others show minimal impacts. Factors that affect the variability of impact are burn severity, erosion processes, the extent of delivery to streams, soil and forest vegetation types and storage and retention of nutrients. The immediate major source of phosphorus comes from leaching of ash deposits, while atmospheric deposition is the dominant immediate source of nitrogen. In the medium term, erosion through the loss of bank stabilisation can also lead to the transport of nutrients into waterways. It can take up to three years for nutrient levels in reservoirs to approach pre-fire levels following a large burn and subsequent major rainfall event. Although there may be some peripheral issues with nutrients entering waterways following bushfires, such as the presence of ammonia, nitrate and nitrite, the predominant issue and concern should be the increase in phosphorus leading to increased cyanobacteria .With cyanobacterial blooms come risks from cyanotoxins; as well as taste and odour compounds.

Metals

The contamination of waterways from metals is mostly an aesthetic issue. This relates to the presence of iron and manganese transported from burnt soil or released from rivers due to waterways; becoming anoxic from reduction of dissolved oxygen. However, there have been examples where other metals such as chromium, arsenic, lead and copper and been released from soils with concentrations that have exceeded drinking water guideline values following post-fire inflows.

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Priority 2

Cyanide

Cyanide can form from the combustion of organic material and present in ash or deposits from the atmosphere. Impacts are most likely short lived and confined to the initial post fire rainfall events.

Polyaromatic aromatic hydrocarbons (PAHs), polychlorinated biphenyls and polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs)

PAHs, PCBs and PCDD/Fs may be produced during combustion in forest fires and released into the atmosphere or deposited in ash and soil. The concern around these chemicals is that they are potentially carcinogenic and can persist in the environment with a tendency to bioaccumulate. However, levels detected in water are generally low and within guideline values.

Anions and cations

Anions and cations released from soils during intense burns can enter waterways following rainfall events. These include sodium, magnesium, calcium, potassium chloride and sulphate. There may be small increases in TDS concentrations but the impacts are likely minimal.

Monitoring

Depending on the scale of the fires in the drinking water catchment sampling programs may be required to understand the change in risk profile of raw water. In terms of priority, ease and value for money a suggested sampling program would include:

- turbidity/total suspended solids;
- DOC;
- nutrient suite; and
- total metal scan.

If there were additional concerns regarding other parameters, this could be extended to include:

- PAHs, PCBs, and PCDD/Fs; and
- cyanide.

While a baseline monitoring program may be useful, the priority is to undertake sampling following significant rainfall events; such as > 50 mm in 24 hours.

In some cases where the soil and sediments have been burnt, the soil becomes hydrophobic and initial runoff is productive - with little absorption into the surface.

For the sampling of rivers and streams, sampling should be undertaken during the 'first flush' or by the use of an automated event peak sampler, or composite sampler over the duration of the event. For sampling in a lake or reservoir, it should be taken at several depths. During inflow events the incoming water may travel beneath the surface at the same temperature as the incoming water. Note that when interpreting results, consideration should be given to the duration of potential exposure as discussed in Khan *et al.*, 2016.

Mitigations and Treatment

Erosion – TSS and turbidity

With high intensity burns in the catchment around the riparian zones, one of the greatest risks is a loss of stability of the banks and gullies leading to mass erosion and release of suspended solids. Once it is safe to do so, it is important the intensity of the fire is quickly established to determine the necessary actions. The main priority for rehabilitation work is to prevent sediment and destructive debris from reaching the streams, and to restore overhanging riparian vegetation. Potential mitigation could include:

- clearing debris to stop it being washed into waterways;
- bank stabilisation works;
- setting up booms and silt curtains to limit sediment entry into the reservoir;
- repairing and revegetating eroded riverbanks;
- restoring riparian vegetation in bands wide enough to trap sediment moving downslope; and
- aerial seeding of grass and planting of shrubs to stabilise bare areas.

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Turbidity

Once suspended solids are in the raw water, they can be removed through the normal conventional treatment processes of flocculation, sedimentation and filtration. However, increased turbidity outside of normal operating ranges will result in reduced flow though the treatment process, increased coagulant use and increased sludge production. In some cases, the water treatment capacity will be exceeded, and treatment may not be possible. For unfiltered supplies, once turbidity increases above 1 NTU, then there is an increased risk to the efficacy of disinfection processes and therefore a risk of pathogen contamination. It is possible that boil water advisories may be triggered. Health agencies should be alerted to this possibility.

Nutrients

There is little to be done practically to manage nutrients once they have entered waterways. The increase in nutrients, especially phosphorus, leads to the risk of cyanobacterial blooms and their metabolites: cyanotoxins, taste and odour compounds. In the absence of ozone/BAC the most effective way to manage the risks from these metabolites in the short term, is through the addition of powdered activated carbon (PAC) to adsorb the compounds upstream of filtration.

Organic Carbon and DBPs

Organic carbon (DBP precursors) concentration can be effectively reduced through ozone/BAC but where absent conventional coagulation and sedimentation processes can be quite effective. Removal by conventional treatment can be increased though enhanced coagulation; whereby the pH of the coagulation process is reduced to preferentially reduce colour (DOC) over turbidity. Once DBPs are formed there is no simple way to reduce concentrations.

Table 1 Impact on treatment processes following catchment fires

Impact	Turbidity	TP	TN	DOC
Increased coagulant use	X			X
Increased sludge production	X			X
Oxidant demand	X		X	X
Increase DBPs	X		X	X
Increase cyanotoxins		X		
Increased taste and odour		X	X	X
Increased operating costs	X	X	X	X

Fire Suppressants

The use of fire suppressants is common in the battle against bushfires to slow the spread of the fires. They can be made from a combination of synthetic detergents, wetting agents, foam stabilisers, organic solvents and corrosion inhibitors. In the assessment of water quality risks post-fire, it is important to review the active ingredients of the products used. Also, to ensure that at the concentrations used over the catchment area chemicals do not exceed any drinking water guideline values or toxicological thresholds.

Further information / references

Deere, D., Leusch F.D.L., Humpage. A., Cunliffe, D., and Kahn, S., Hypothetical scenario exercises to improve planning and readiness for drinking water quality management during extreme weather events. Water Research, 111 (2017), 100-108.

Kahn, S., Deere, D., Leusch F.D.L., Humpage, A., Jenkins, M., and Cunliffe, D., Identify and Assess the Water Quality Risks from Extreme Events, Water Research Australia Report 1063 (2016).

Smith H., Cawson J., Sheridan G. and Lane P., Desktop review – Impact of bushfires on water quality, 2011. https://www.waterquality.gov.au/issues/bushfires/impact-review

Smith H., Sheridan G.J., Lane, P.N.J., Nyman, P. and Haydon S. Wildfire effects on water quality in forest catchments: A review with implications for water supply, Journal of Hydrology, 396, (2011), 170-192.