

MANAGING WATER QUALITY RISK DURING EXTREME EVENTS (BUSHFIRES AND FLOODS): RESULTS FROM A NATIONAL SURVEY

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KEYWORDS

Extreme events, water quality indicators, risk management

ABSTRACT

Extreme events can have unpredictable effects on source water quality, both in terms of impacts on commonly measured water quality indicators, as well as the possible introduction of contaminants of emerging concern into catchment runoff. In this project we reviewed existing knowledge assessing impacts on source water quality due to bushfires and floods. We also carried out a survey to understand current water utility responses during a bushfire and/or flood/storm event. Our results provide new insights into common challenges for the analysis of samples collected during these extreme events and provide guidance on the optimum analytical methodology for key water quality indicators.

INTRODUCTION

The frequency of extreme weather events, including floods, storms, and wildfires, has intensified globally over the recent decades primarily due to climate change (IPCC, 2014; Wang et al., 2022). These extreme events can directly impact drinking water quality, both in terms of commonly measured water quality indicators, as well as the possible introduction of contaminants of emerging concern into catchment runoff. Additionally, indirect impacts of extreme events on water supply and water quality may include damage or loss of water supply infrastructure and/or water treatment plants, power and communication outages, and inaccessibility to water storages such as dams.

The Australian Drinking Water Guidelines (ADWG, 2011 version 3.8) provide some guidance on managing water quality during emergencies and disasters. However, the ability to make informed decisions during extreme events may be compromised due to the level of unpredictability in raw water characteristics. Accurate and timely analysis of key water quality indicators is an

important aspect of mitigating risks. That is, without reliable analysis, water quality managers lack relevant information to mitigate and model risks to drinking water safety.

In this study, we have surveyed Australian water utilities and regional councils to understand how risks to water quality are managed during extreme events. In addition to an assessment of current and future risk of extreme events to drinking water quality, the survey provides insight into the water quality parameters considered of highest concern, and how monitoring programs may be modified to achieve safe drinking water quality.

METHODOLOGY

The review of existing knowledge surrounding impacts on source water quality from bushfires and floods in Australia focussed on relevant previous Water Research Australia (WaterRA) projects and relevant recent publications (Khan et al., 2016; Raelison et al., 2023; Saaristo et al., 2024; Sagar et al., 2025). Analytes of concern during bushfires and floods, were selected to characterise changes in source water quality considering both the impact on treatment processes and health risks post treatment.

A survey to understand current water utility responses during bushfires and floods/storms, including the water quality parameters currently measured, as well as to identify relevant case studies was sent to WaterRA industry members and relevant state water directorates. The survey questionnaire focused on: 1) demographic information, including the population that the water utility serves and the total area of operation, 2) an evaluation of current and future risks from extreme events, 3) current management practices for bushfires and storms/floods, and 4) identification of relevant case studies and datasets from past events. The survey questionnaire can be found in Sagar et al. (2025).

RESULTS AND DISCUSSION

Key analytes to characterise changes in source water quality

Table 1 summarises the key analytes identified that characterise changes in source water quality for both bushfire and flood, considering both the impact on treatment processes and health risk post-treatment. Of the 55 analytes or indicators identified, 24 were for flood only, 17 were for bushfire only and 14 were for both bushfire and flood. These analytes are classed into physical and chemical parameters, nutrients, pesticides, disinfection by-products, cyanotoxins, pathogens, trace elements, cations, and other.

Survey Respondents

Eighteen water utilities and regional councils participated in the survey. The population served by the participating water utilities ranged from 3300 to greater than 5 M, and the total area of operations of individual water utilities varied from 2358 km² to more than 2.2×10⁶ km². The approximate coverage of the population for each state estimated from survey responses is shown in Figure 1. The reported use of surface water as a water source ranged between 16-100%, with the median of reported values being 95%. Twelve water utilities reported use of groundwater, ranging between 1 and 82%, with the median of reported value being 5%. Groundwater as a source water was more than 20% for four water utilities. Six water utilities reported the use of desalinated water (0.1%, 0.8%, 2.4%, 20% and two unquantified). Only two respondents reported use of recycled water, and this was estimated to be less than 1% of all source water used. Fourteen water utilities expected that their mix of source waters would change in the next 10 years, while two did not expect a change, and two were less definite about possible changes. Of those utilities that did expect a change in the next 10 years, seven indicated that they expected the ratio of existing water sources (largely surface water and groundwater) to change, while eight indicated that desalinated water and or recycled water were likely to be increased or introduced to make water supplies more climate independent.

In the last five years, the drinking water quality of four respondents was impacted by one bushfire event, while six had been impacted by two bushfire events. All water utilities reported drinking water quality being impacted by multiple storm or flood events each year. Most respondents had experienced between 2 and 6 events each year, while one utility reported 20-50 flood/storm events in the last five years.

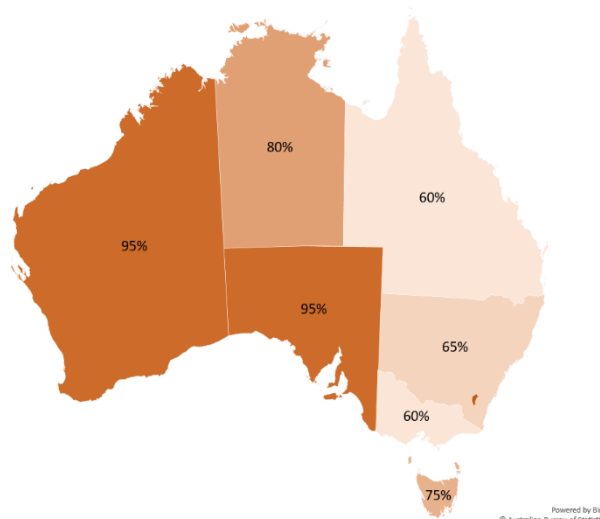


Figure 1: Estimated coverage of population for each state based on survey responses

Risk from bushfire

All respondents considered bushfires a risk to their drinking water supplies, particularly when considering water quality, quantity, and infrastructure. As an example, one respondent reported that a rainforest in a sub-tropical catchment which had never previously been subjected to bushfires was impacted by bushfire in 2019, and this change in susceptibility was attributed to climate change. Another respondent noted that prescribed burns were used to reduce the fuel load in catchments, although this could be a challenge for catchments with elevated fuel loads.

The major impacts on quality of source waters during bush fires identified by respondents were increased turbidity, and increased mobilisation of sediments and contaminants, including metals and fire suppressants in post-fire runoff. The loss of biodiversity due to forest fires also inhibits natural water treatment functions, including reduced catchment run-off as forests and vegetation regrow. Surface water supplies can show increases in dissolved organics, turbidity, colour, nutrients, increased algal growth, and DBP formation potential, an increased likelihood of deoxygenated waters in rivers, and potential taste and odour issues from melted plastic components. Five respondents indicated that changes in water quality made source water in their catchments more difficult to treat or even untreatable, particularly for water supply systems which had minimal or no engineered filtration infrastructure. Damage to remote assets (e.g. water monitoring stations) and a lack of access to these assets can also reduce the information available to make operational decisions.

In addition to impacts on water quality, water quantity can also be impacted if bushfires destroy water supply and treatment infrastructure, including power

and communications networks, leading to supply interruption. Water quantity can also be put at risk if that water is used for firefighting. One respondent reported that excessive drawdown on one town's water supplies would have left the town with insufficient reserves, if the bushfire had moved towards and into populated areas.

Risk from storms and/or floods

All respondents considered storms and/or floods as a risk to their drinking water supplies, with one respondent indicating that all their drinking water treatment plants source raw water from rivers, which means the entire water supply system is at risk during flood events.

Like bushfires, the risks posed by floods to source waters included changes in water quality, quantity and damage to infrastructure. The major concerns for source water quality were the mobilisation of contaminants, including pathogens such as *Cryptosporidium* spp., and *E. coli*, increases in nutrients and organic matter, high turbidity (in one case more than 10,000 NTU), and high colour. One respondent reported that remote communities had experienced deterioration in water quality from groundwater bores during high rainfall periods due to rapid ingress through disused bores and ground seepage, and inundation of head works. Changes in water quality were linked with increased treatment challenges, particularly high chlorine demand and Australian drinking water guideline non-compliance. Additional challenges to managing water quality during a flood included the rapid rate of change in water quality being difficult to monitor, and loss of access to infrastructure and monitoring equipment.

Significant floods can damage water supply and treatment infrastructure (e.g., inundation of assets such as bores, pump stations, and switchboards), cause power outages, and also cause damage (e.g. erosion and sediment smothering) to natural assets, such that natural ecosystem function is impaired. In addition to impacts on source waters, flood water can penetrate the drinking water supply if there is a loss of pressure within water supply infrastructure.

Current preparedness for management of water quality during extreme events

Participants were asked about their current level of preparedness with respect to monitoring water quality during both bushfire and storm and/or flood events. Most respondents had at least some plans to monitor water quality during these extreme events (Figures 2 and 3). For bushfires (Figure 2), six respondents (33%) had a fully developed plan for water quality monitoring that has been revised and informed by application to a real-life events, while two (11%) had a comprehensive plan that had not been applied to a real life event, nine (50%) had some plans for some aspects of monitoring water quality, and only one respondent (6%) had no specific plan.

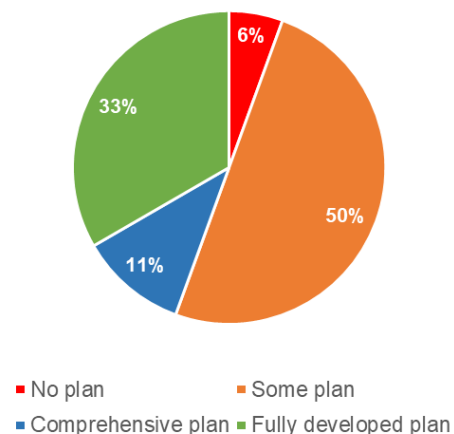


Figure 2: Preparedness for water quality monitoring during bushfires

For storms and/or floods (Figure 3), eight respondents (41%) had a fully developed plan for water quality monitoring that has been revised and informed by application to a real-life events, while two (12%) had a comprehensive plan that had not been applied to a real life event, seven (39%) had some plans for some aspects of monitoring water quality, and only one respondent (6%) had no specific plan. One respondent reported that, while they did not have a specific plan for flood events, routine operational plans did address changes in water quality that occur with higher flow.

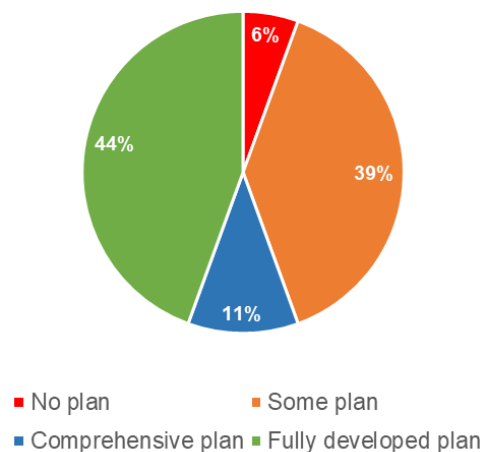


Figure 3: Preparedness for water quality monitoring during storms or floods

Management of water quality during fire events

To understand current water utility management strategies for water quality during bushfires, respondents were asked about their immediate and long-term water quality concerns, and to rank their level of concern of different analyte classes identified (Table 1).

Figure 4 shows the level of concern for different analyte classes immediately after a bushfire event (days-weeks). Of highest concern were turbidity or colour, DOC, BOD or COD, pathogens, and DBPs,

followed by nutrients, metals, and algal toxins. No respondents considered pesticides or pH/alkalinity of very high concern immediately after a bush fire.

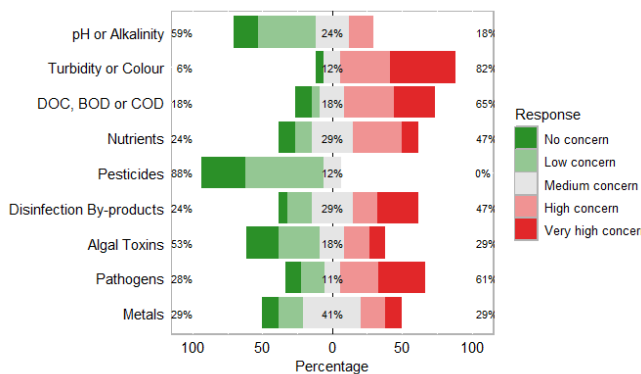


Figure 4: Analyte classes of concern immediately after a fire event

Most of the immediate water quality concerns reported by respondents were related to these analyte classes. However, several noted that it was the first rainfall or storm event after the bushfire event that posed the most risk from run-off into water supplies. One respondent that extracted source water from rivers noted the ability to turn off extraction to allow highly contaminated water to pass through, although another noted that the duration of the poor-quality water in the river could be a concern. Other specific chemicals or chemical classes that were identified of being of immediate concern were hydrocarbons, PFAS, DOC, increased potential for DBP formation, and ensuring there was adequate free chlorine in the network, due to the increased chlorine demand generated by source waters. Three respondents noted concerns about fire-fighting chemicals and fire retardants, with one reporting that understanding what chemicals were used by emergency response agencies was very important. One noted that they refused to support the use of fire retardants during the Black Summer fire response as retardant suppliers were unwilling to provide Safety Data Sheets to help assess risks to drinking water supply catchments.

Other immediate concerns were the ability to maintain access to water treatment plants and the availability of treatment chemicals to ensure continued drinking water treatment, and loss of infrastructure (e.g. tanks, pumps, or breaks in pipelines) that could lead to depressurisation and therefore network contamination, and loss of water supply to firefighting.

Figure 5 shows the level of concern for the different analyte classes in the longer-term aftermath of a fire event (weeks-months). Of highest concern were turbidity and colour, DBPs, nutrients, DOC, BOD or COD, and to a lesser extent nutrients, algal toxins, pathogens and metals. Again, no respondents considered pesticides or pH/alkalinity of very high concern in the longer term after a bushfire. Overall, fewer analyte classes were assessed to be of very

high concern over the longer term compared to immediately after a bushfire event. Considering both the immediate and longer-term aftermath of bushfire events, pesticides were the class of analytes of lowest concern.

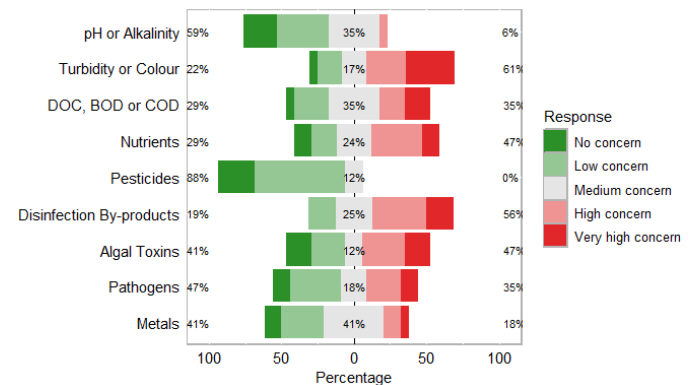


Figure 5: Analyte classes of concern in the longer-term after a fire event

Most of the longer-term water quality concerns reported by respondents were related to the identified analyte classes, with the risk of eutrophication and subsequent algal blooms being specifically mentioned by six respondents. Five water utilities mentioned issues with taste and odour, with one specifically identifying taste and odour from melted plastic components (e.g. burnt water meters in the water supply network). Low dissolved oxygen in water supplies was mentioned by two respondents, with one noting that it led to manganese and iron remobilisation in bottom waters of reservoirs during periods of stratification in summer. Other specific chemicals or chemical classes that were identified of being of longer-term concern were similar to those reported as being of immediate concern, including fire retardants/contamination from the emergency response agencies, PFAS, temporary increases in THMs and novel DBPs, hydrocarbons, and chemical by-products from bushfire.

Other challenges impacting water quality in the medium to long term were waterway stability and catchment management to minimise sediment and runoff into source waters. It was noted that the impact of a bushfire is very catchment specific, and, additionally, the scale, intensity and duration of the bushfire all impact catchment recovery time. It was further observed that the catchments become warmer due to the loss of tree cover during bushfires.

Sixteen of the eighteen (88%) participating water utilities said that they changed their water sampling regime during and after a bushfire event. One of the respondents who answered 'no' indicated that they only did additional sampling if system integrity was suspected to have been impacted. Ten respondents indicated that they increased frequency or extent of sampling, while seven respondents indicated a change to the analytes being tested compared to normal. Specific actions mentioned by respondents included: increased raw and treated water

monitoring, increased ad hoc sampling for turbidity and metals to understand reservoir dynamics, increased frequency of hydrocarbon testing, more regular jar tests, THM monitoring, depth-profiling, flow telemetry and targeted water quality testing to assess the degree of poor-quality water, and characterisation of ash and readily transported materials to help determine potential impacts after heavy rainfall. The increased frequency of sampling and enhanced monitoring was dependent on the particular circumstance of the bushfire, and the scale and intensity of any subsequent rainfall events. It was also noted that the safety of sampling officers was paramount.

Additional sampling information was most frequently used by water utilities to optimise treatment processes (nine respondents), but was also used to make decision about which water source to use (six respondents) and identify potential contamination or health impacts (three respondents). Sampling information was also compared to baseline results, used both to inform further sampling and monitor catchment recovery and management. Most water utilities return to their normal monitoring plan when the water quality results return to baseline, or reach steady state, or are within guideline limits. One water utility also identified that monitoring may cease when there are no longer significant challenges to treatment infrastructure, while one noted that additional monitoring may cease if they had budget constraints.

Management during storm and/or flood events

Figure 6 shows the level of concern for the different analyte classes immediately after a storm/flood event (days-weeks). Of highest concern were pathogens, turbidity or colour, DOC, BOD or COD, and DBPs, followed by nutrients, metals, and pH of the source waters. All participating utilities classified pathogens as medium concern to very high concern. No respondents considered pesticides or algal toxins of very high immediate concern.

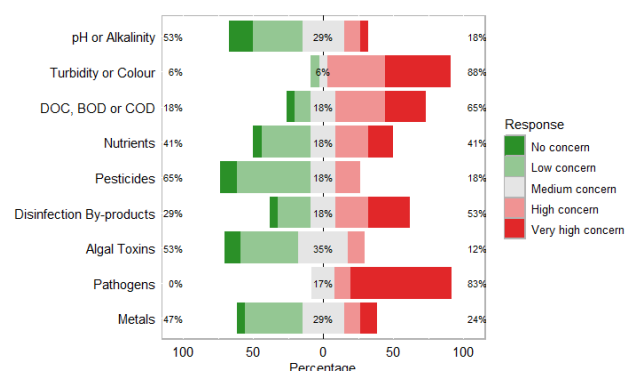


Figure 6: Analyte classes of concern in the immediately after a storm and/or flood event

Most of the immediate water quality concerns reported by respondents were related to the identified analyte classes (Table 1), particularly pathogens and turbidity, as well as understanding

how changes in source water quality influence treatment operations and the need to bring other replacement sources on-line. One respondent noted concern about the ability of their water treatment plants to treat highly turbid waters. Other immediate concern were *E. coli* and bacteria, hydrocarbons, and taste and odour compounds, and ensuring there was adequate free chlorine to maintain additional protection against pathogens. One respondent also noted a broad concern about contamination sources such as sewer overflow, farm run-off, and drums of chemicals in the source waters.

Nine respondents noted additional concerns related to increased contaminants or ingress of contaminants into the distribution system through tank damage or ingress of flood waters into the network. Six respondents noted concerns about the ability to continue water treatment through lack of plant access, infrastructure damage or power loss.

Figure 7 shows the level of concern for the identified analyte classes in the longer-term after a storm and/or flood event (weeks-months). Of highest concern were pathogens, DBPs, turbidity or colour and nutrients followed by algal toxins, DOC, BOD or COD and the pH of source waters. No respondents considered pesticides or pH/alkalinity of very high concern in the longer term after a storm/flood event. Overall, a higher percentage of analytes were classified to be of medium to very high concern immediately (days-weeks) after a storm/flood event compared to the longer-term (weeks-months).

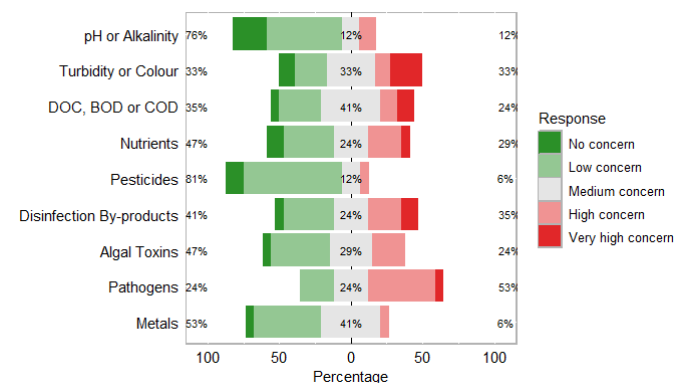


Figure 7: Analyte classes of concern in the longer-term after a storm and/or flood event

Most of the longer-term (weeks-months) water quality concerns reported by respondents were related to the analyte classes in Figure 7. Turbidity was noted specifically by eight respondents, although one also noted that turbidity typically reduced relatively quickly, while elevated DOC can continue for a longer time. Four respondents noted issues with elevated DOC/organic load, particularly leading to increased DBP formation. Other specific chemicals or chemical classes of longer-term concern were largely similar to those reported to be of immediate concern, including taste and odour compounds, and ensuring there was adequate free chlorine, but they also included salinity and bromide

for some systems. It was also observed that changes in algal growth and algal toxins pose a longer-term risk compared to immediate effects from floods. One respondent noted that the impacts of floods and/or storms are usually more short term than impacts from bush fires. Another noted that flooding was a relatively routine event for them and that the very high turbidity and DOC spikes that are a part of the flood were manageable for a few days or a week or two.

Other challenges impacting water quality in the medium to long term were changes to the ecosystem and the ability for a storage to maintain its buffering capacity, particularly if there was erosion/ damage to riparian buffers, and therefore the need for ongoing management of contaminated source waters, particularly if no alternatives are available.

Nine of the eighteen participating water utilities said that they changed their water sampling regime during a storm or flood event, while four said they modified their sampling regime if the flood had impacted system integrity or if source water changed drastically, and four did not change their sampling regime. One respondent noted that their monitoring program was designed to include expected seasonal events (e.g. wet and dry season). Another respondent noted that the storm events they experienced were typically short and that it was typically unsafe to send staff out to sample during the storm event, meaning that additional monitoring was not undertaken.

Nine respondents indicated that they increased the frequency or extent of sampling, while only two respondents indicated a change to the analytes being tested compared to normal, with both of these respondents focussed on additional monitoring of pathogens. Specific actions mentioned by respondents included: increased sampling frequency if water quality was known to be changing quickly, targeted sampling if ingress into infrastructure was suspected, and requesting expedited turnaround times from laboratories for analyses. One respondent indicated that their wet weather monitoring plans were focussed on understanding the treatability of source waters and any associated pathogen risks, while two respondents indicated that additional jar testing was undertaken to ensure treatment plant operators were prepared for changes in source water quality. Online monitoring was considered important given the potential lack of access or safety concerns if dams were spilling and to monitor rapid changes in water quality.

Additional sampling information was most frequently used by water utilities to optimise treatment processes (seven respondents) but was also used to make decisions about which water source to use (four respondents) and to identify potential contamination or health impacts (five respondents). Two respondents specifically mentioned the potential for water quality data to be used to determine whether the community should be issued

with water conservation or boil water alerts. Sampling information was also compared to baseline data in order to determine potential issues with the aesthetic qualities of the drinking water being supplied. All water utilities reported returning to their normal monitoring plan when the water quality results return to baseline, or reach steady state, or are within reporting limits. While most responses suggested that parameters returned to normal ranges relatively quickly, one respondent provided an example of a lake water supply in which the water quality took several years to return to pre-flood conditions, and the increased sampling regime was continued during that time.

CONCLUSION

Analytes of concern during fire events and analytical challenges

The short- and long-term water quality challenges and management needs after a bushfire event are summarised in Figure 8. Following a bushfire, water quality issues/challenges are typically observed after the first significant rainfall after the fire event, and these impacts particularly affect water reservoirs (rather than rivers), where sediment runoff and turbidity persists. Following rainfall, there is an increased likelihood of altered reservoir dynamics, eutrophication and algal blooms, with DBPs in the network being the highest class of chemicals of concern, after turbidity and colour. Based on survey responses, DBP formation is monitored by the analysis of THMs in treated water. However, changes in the profile of organic matter may lead to the formation of other classes of DBPs, particularly nitrogen-containing DBPs that may form from the chlorination or chloramination of algal or organic matter, and this may alter the health risk from DBPs in treated water.

Further assessment of the use of fire retardants used during bushfires, and the development of screening methods to identify their presence in catchments following bushfire, would enable water utilities to better assess the risk associated with their use.

Analytes of concern during storm and/or flood events and analytical challenges

The short- and long-term water quality challenges and management needs after a storm and/or flood event are also summarised in Figure 8. Immediate water quality concerns following storms or flooding are focussed on the microbial safety of drinking water, either from the additional load of pathogens present in affected source waters, or from challenges to treatment and disinfection due to higher turbidity or DOC loads. Given the importance

of analytical turn-around times in such instances, further investigation of the appropriate uses for portable/rapid eDNA or PCR equipment may enable water utilities to make faster and more informed decisions. The effect of matrix effects, such as the effect of elevated turbidity and colour, on such analysis requires further investigation.

Another area of unknown risk is the impact of contamination to source water from such sources as sewer overflows, farm run-off, and drums of chemicals. Analysis of such events is difficult, given that the impacts of any contamination are likely to be transient. Here, novel techniques for unknown chemicals, such as effect-based monitoring or non-targeted analysis, may have utility but are more suited to longer-term assessments of chemical risk.

Increased DBP formation in treated drinking water can result from elevated DOC concentrations in source waters. Similar to bushfires, DBP formation is monitored by analysis of THMs in treated water. However, it might be useful to investigate a wider suite of DBPs in such instances, especially if the salinity of source waters has increased from land clearing, as this may result in increased formation of brominated or iodinated DBPs.

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Fire Floods/ storms	Short Term Challenges • Impact of turbidity/ DOC on treatment and/or disinfection • Fire retardants	Long Term Challenges • Turbidity, nutrients, algal blooms, water body function • Taste and odour compounds, DBPs	Management Needs • Treatment optimization • Water source selection • Catchment health
	Short Term Challenges • Pathogen risks • Impact of turbidity/DOC on treatment and/or disinfection • Unknown contamination sources and ingress into distribution system	Long Term Challenges • High DOC/organic load • Algal blooms • Taste and odour compounds, DBPs	Management Needs • Expedited turn around times for pathogen analysis • Treatment optimization • Water source selection • Public health risk

Figure 8: Summary of challenges and management needs for fires and storm and/or flood events

Table 1: Key analytes to characterise changes in source water quality as identified from relevant WaterRA projects and some recent publications including Khan et al. (2016); Raoelison et al. (2023); Saaristo et al. (2024)

Class	Analytes	Risk Factor	Class	Analytes	Risk Factor
Physical and chemical parameters	Alkalinity	Flood	Trace elements	Aluminium (Al)	Fire
	Biochemical & Chemical oxygen demand	Flood		Antimony (Sb)	Flood
	Dissolved organic carbon	Flood/Fire		Arsenic (As)	Fire
	pH	Flood		Barium (Ba)	Fire
	Total dissolved solids	Flood/Fire		Boron (B)	Flood
	Turbidity	Flood/Fire		Cadmium (Cd)	Fire
	UV-absorbing compounds	Flood/Fire		Chromium (Cr)	Fire
	Colour	Flood/Fire		Cobalt (Co)	Flood
Nutrients	Total Nitrogen	Fire		Copper (Cu)	Flood
	Total Phosphorous	Fire		Iron (Fe)	Flood/Fire
Pesticides	Herbicides such as 2,4-Dichlorophenoxy-acetic acid (2,4-D), atrazine, simazine, diuron, glyphosate, MCPA, dicamba, metolachlor, sulfometuron-methyl, metsulfuron-methyl, metamitron, hexazinone	Flood/Fire		Lead (Pb)	Flood/Fire
				Lithium (Li)	Flood
				Manganese (Mn)	Flood/Fire
				Mercury (Hg)	Fire
	Insecticides such as chlorpyrifos, diazinon, dimethoate, methylparathion, N,N-diethyl-m-toluamide (DEET), imidicloprid, indoxacarb	Flood/Fire		Nickel (Ni)	Flood
				Selenium (Se)	Flood
				Tin (Sn)	Flood
				Titanium (Ti)	Flood
	Pesticide-Synergists such as n-Octyl bicycloheptene dicarboximide (MGK-264) and o-Phenylphenol	Flood		Vanadium (V)	Flood
				Zinc (Zn)	Flood
			Cations	Calcium (Ca)	Fire
				Magnesium (Mg)	Fire
Potassium (K)	Fire				
Sodium (Na)	Fire				
Disinfection by-products	Bromodichloromethane	Flood/Fire	Chloride	Fire	
	Bromoform	Flood/Fire	Nitrate	Flood	
	Chloroform	Flood/Fire	Phosphate	Flood	
	Dibromochloromethane	Flood/Fire	Sulfate	Fire	
Cyanotoxins	Cylindrospermopsin	Flood	Other	Ammonia	Fire
	Microcystin	Flood		Cyanide	Fire
	Saxitoxin	Flood		Per- and polyfluoroalkyl substances (PFAS)	Flood
Pathogens	<i>Cryptosporidium</i> spp.	Flood		Polyaromatic hydrocarbons (PAHs)	Fire
	<i>E. coli</i> & <i>Enterococci</i> – faecal indicator bacteria	Flood			