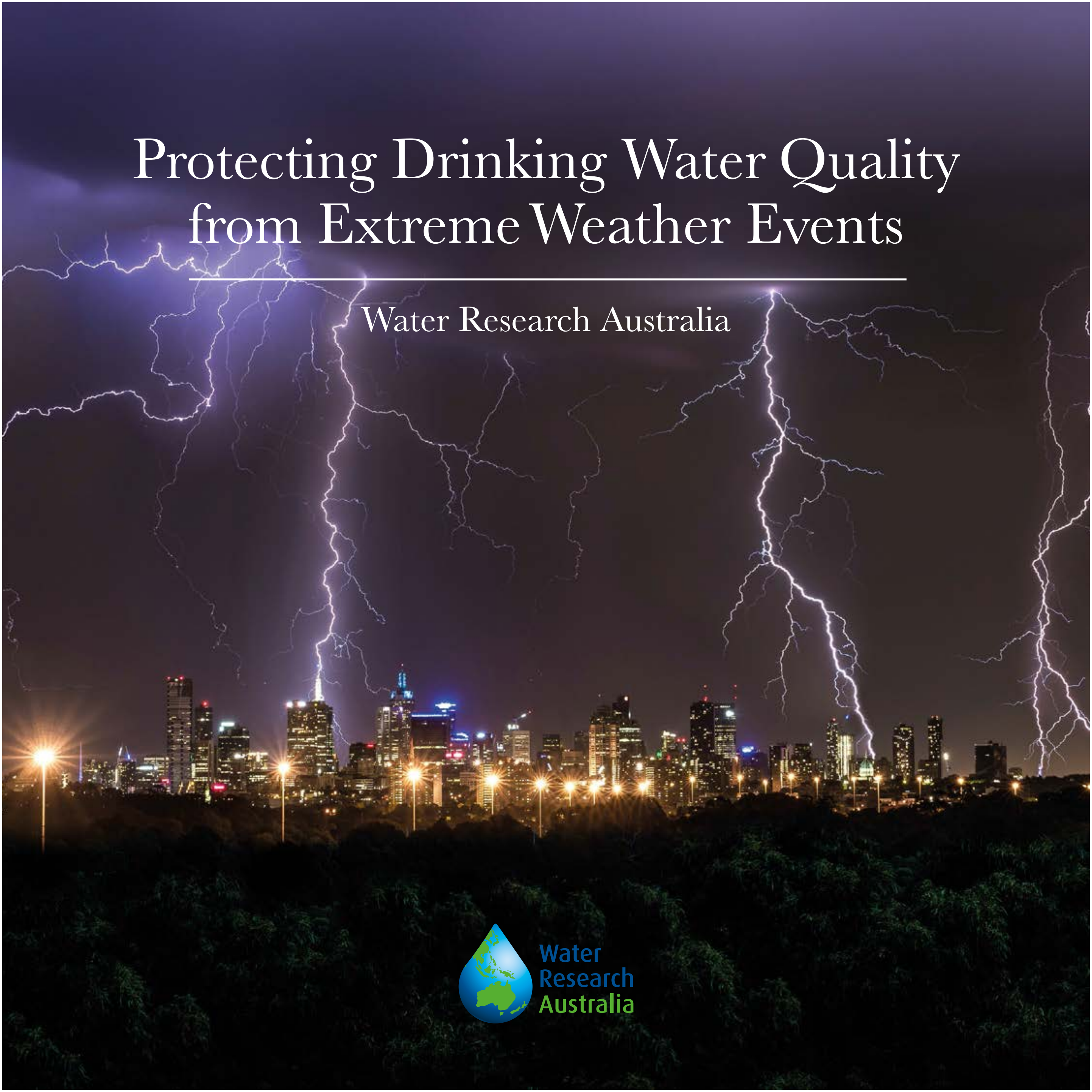

Protecting Drinking Water Quality from Extreme Weather Events

Water Research Australia

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Foreword

The Australian water industry has played a leading role in the incorporation of a risk-based management framework to underpin safe and reliable drinking water supply. This was achieved by the development of the Framework for Management of Drinking Water Quality, which first appeared in the 2004 revision of the Australian Drinking Water Guidelines (ADWG). While that Framework is applicable to the management of drinking water quality under all conditions, there is evidence to indicate that a range of extreme weather events pose particular challenges to drinking water quality.

In 2013, Water Research Australia funded a research project to "Identify and assess the water quality risks from extreme events" (WaterRA Project 1063-12). The aim of this project was to undertake research to support the development of specific guidance for the Australian water industry to manage threats to drinking water quality from extreme weather events. The outcomes of this research were presented in the final report for WaterRA Project 1063-12 and four key scientific journal manuscripts are now completed or in preparation:

1. Khan SJ, Deere D, Leusch FDL, Humpage A, Jenkins M and Cunliffe D (2015) Extreme weather events: Should drinking water quality management systems adapt to changing risk profiles? ***Water Research,*** 85, 124-136. DOI: 10.1016/j.watres.2015.08.018
2. Khan SJ, Deere D, Leusch FDL, Humpage A, Jenkins M Cunliffe D, Fitzgerald S and Stanford B (2016) Managing Safe Drinking Water during Extreme Weather Events – Lessons from Australia (***Submitted for publication, March 2016, available on request***).
3. Deere D, Leusch FDL, Humpage A, Cunliffe D, Khan SJ (2016) Hypothetical scenario exercises to improve planning and readiness for drinking water management during extreme weather events (***Submitted for publication, April 2016, available on request***).
4. Leusch FDL, Humpage A, Deere D, Cunliffe D, Khan SJ (2016) Short term guidelines for drinking water quality during extreme events (***In Preparation, April 2016***).

In addition to describing the research that was undertaken, these four manuscripts provide the justification and scientific basis for the development of this document. It is intended that this document will provide high-level guidance on the steps that can be taken by drinking water managers to improve the resilience of their systems to extreme weather events. Readers are encouraged to consult the four research articles for more specific information.

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Why is specific guidance on extreme weather events needed?

Extreme weather events include heavy rainfall and floods, cyclones, droughts, heatwaves, extreme cold, and wildfires. Each of these types of events can potentially impact drinking water quality by affecting water catchments, storage reservoirs, the performance of water treatment processes or the integrity of distribution systems.

There is now broad scientific consensus that, with the continuation of greenhouse gas warming over the 21st century, it is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions (IPCC 2014). These climate change impacts will amplify existing risks, and create new risks for natural and human systems. The Intergovernmental Panel on Climate Change (IPCC) has identified important key risks for various global regions, including in some cases, increased drought-related water shortages, as well as increased damage from floods and wildfires (IPCC 2014).

Current evidence indicates global increases in the frequency and magnitude of high temperature extremes, together with more frequent and intense heavy rainfall events in many, but not all, global regions (Goodess, 2013). Consequently, some regions are projected to become more prone to more intense rainfall, while others will become more prone to drought (Cook *et al.*, 2014). Recent analysis suggests that already about 75% of the moderate daily hot extremes, and about 18% of the moderate daily precipitation extremes over land, are attributable to climate change (Fischer & Knutti, 2015). Pacific Ocean El Niño events are a prominent feature of climate variability and are associated with severely disrupted weather patterns, leading to tropical cyclones, drought, wildfires, floods and other extreme weather events worldwide (Cai *et al.*, 2012). Recent modelling predicts doubling in El Niño event occurrences in the future as a result of greenhouse gas warming (Cai *et al.*, 2014).

Extreme weather events may adversely impact on drinking water supplies in a variety of ways, leading to water quality impacts, including increased concentrations of suspended material, organic matter, nutrients, inorganic substances and pathogenic microorganisms in source waters.

A systematic review identified eighty-seven waterborne outbreaks involving extreme water-related weather events (Cann *et al*., 2013). Heavy rainfall and flooding were the most common extreme weather events that preceded waterborne outbreaks, which often resulted from the contamination of drinking-water supplies.

Direct impacts to water quality from extreme weather may be relatively simple to identify, but indirect impacts from extreme weather or changing trends over time can be overlooked, especially when they occur months, or even years, after the onset of the particular event. Changes to temperature and precipitation patterns can increase the potential for wildfires, encourage invasive species or increase forest mortality, resulting in both short-term impacts on water quality and long-term impacts to water catchments.

It is possible to design and operate systems to mitigate foreseeable extreme events. Many water quality impacts from extreme weather events may be successfully managed by existing water treatment plants and, therefore, do not lead to water quality impacts being experienced by customers, provided the treatment plants have been adequately designed and are operated for the local circumstances. However, some extreme events may impose additional burdens on treatment facilities, requiring additional power consumption, chemical use, maintenance or waste production. They may also represent an elevated level of source water risk and require additional risk management activities by water utilities, regulators and others to protect customers.

In some cases, extreme weather events can adversely impact water supply systems, such that normal household water services may not be maintained. These circumstances may also have public health impacts. Furthermore, extreme weather events can damage electrical, communication and transportation infrastructure, leaving water supply systems and operations vulnerable to other water quality impacts.

Small scale water services, using surface water resources (rivers and lakes) for drinking water production may be particularly vulnerable to short term events due to their low adaptation capacity, and a relative lack of trained personnel and technical knowledge, compared to major centralised systems.

A summary of water quality and quantity consequences of extreme weather events and possible mitigation strategies is presented in Table 1 (Khan *et al*., 2015). Australian experience has shown that even when individual weather events may not be considered 'extreme', combinations of events can present extreme and difficult-to-predict circumstances (Khan *et al*., 2016).

Table 1. Water quality and quantity consequences of extreme weather events and possible mitigation strategies (Khan *et al*., 2015).

Extreme event	**Duration of effect after the event[1]**	**Adverse supply impact**	**Effective mitigation strategies**
Heavy rainfall and floods	Short to moderate	• Increased pathogen and contaminant concentrations • Elevated turbidity due to increased particulate and soluble substances in storm runoff • Sewage system overflows • Decreased disinfection efficacy • Damage to infrastructure, including electrical supply • Staff cut off from treatment plants and other work locations • Very short retention times in reservoirs due to short-circuiting	• Additional or increased disinfection processes • Implementation of enhanced treatment options prior to a forecast event Issuing of boil water advisories • Alternate delivery of potable water (e.g., tankers) • Supply of point-of-use filtration devices and personal water quality testing kits • Pre-filtration of surface waters prior to intake in drinking water plants • Diversifying water sourcing options
Superstorms and high winds	Short	• Similar to "heavy rainfall and floods" above. • Loss of key staff due to transport difficulties or damage to their own property.	• Similar to "heavy rainfall and floods" above, plus: • Plan to have alternate staff available on call or accessible remotely • Building redundancy into water supply systems, including back-up power generators • Availability of alternate water sources
Drought	Moderate	• Increased nutrient loads after extended period of drought • Large "flushes" of organic carbon once rainfall occurs • Elevated risks of algal and cyanobacterial blooms • Intrusion of saltwater in coastal area groundwater or intrusion of saline groundwater into inland surface water, which can render water unpalatable and require significant treatment changes, and can lead to increased brominated disinfection by-products	• Increased monitoring of surface water reservoirs for signs of algal or cyanobacterial blooms • Diversifying water sourcing options • Additional filtration in early stages of drinking water production
Extreme heat	Short to Moderate	• Elevated risks of algal and cyanobacterial blooms • Accelerated loss of disinfectant residual in distribution system • Early onset of nitrification in chloraminated systems • Increased peak demand	• Diversifying water sourcing options • Careful monitoring and application of disinfectant • Vertical mixing of water supply reservoir • Stricter nutrient management in the catchment
Wildfires	Short to Long	• Destruction of treatment equipment and other hardware • Staff cut off from treatment plants and other work locations • Increased magnitude of storm runoff • Increased nutrient and contaminant loads • Increased organic carbon • Elevated risks of algal and cyanobacterial blooms • Elevated microbial activity and DOC transformation • Presence of fire-fighting chemicals	• Diversifying water sourcing options • Additional filtration in early stages of drinking water production • Activated carbon treatment • Careful monitoring and application of disinfectant • Additional monitoring of contaminants • Prevention of particulate matter entering water-courses (eg straw bales, construction of swales)
Unseasonable extreme cold	Moderate to Long	• Salinisation from de-icing salts • Lake destratification and mixing • Intake ice blockages • Distribution system failures	• Careful control of road surface runoff • Enhanced distribution system monitoring and maintenance

[1] short = days to weeks, moderate = weeks to months, long = years

Planning and preparedness

The challenges presented to drinking water managers from extreme weather events are diverse, and often complicated, but not entirely unpredictable. Indeed, there are many lessons to be learned from previous experience in managing extreme weather events, and from the more fundamental investigations of water quality impacts. From those lessons come opportunities to improve planning and preparation, and to gain a more thorough understanding of the water quality and quantity consequences of extreme weather events, which may help water utilities adopt effective mitigation strategies immediately prior to, and during, extreme situations.

Leading change and coordinating effort

In any organisation, fundamental and structural change must come from the leadership. Focused and dedicated leadership will be required for the proper coordination of extreme weather event response. As a first step, water management organisations should develop a formal whole-of-organisation strategy for building resilience to extreme events. Having such a strategy endorsed at a Board or senior management level will send a strong message to all personnel that improving resilience is a core activity of the organisation. Objectives to achieve improved resilience should be clearly stated and support should be provided to key departments and individuals for identified necessary improvement activities.

Australian Drinking Water Guidelines and the Framework for Management of Drinking Water Quality

The ADWG provide guidance for the safe management of drinking water in the "***Framework for Management of Drinking Water Quality"*** (NHMRC & NRMMC 2011).

Implementation of the ADWG Framework assists Australian water managers to effectively manage impacts from extreme weather events. The Framework requires water managers to develop a detailed understanding of their water supply systems, including potential hazards and hazardous events in catchments, treatment systems and distribution systems. Furthermore, the Framework requires the development and implementation of preventative measures to manage and protect against the risks associated with identified hazards and hazardous events.

A detailed understanding of drinking water catchments and their potential responses during extreme weather events can significantly aid planning. An understanding of existing water supply systems, including catchment characteristics, the ability to transfer water between storages and existing or available treatment capabilities has facilitated the management of some extreme events (Khan *et al.*, 2016). For example, during the 2009 Victorian bushfires, a water quality risk assessment and a decision to transfer water between reservoirs were aided by a thorough understanding of the reservoirs throughout the catchments. Extensive modelling was undertaken prior to the bushfires, which augmented understanding of the behaviour of these reservoirs, and thus facilitated decision-making and water quality management. Wildfire simulation modelling and geospatial risk assessment methods could have been adopted to improve the prediction of water quality impacts and prioritise at-risk water catchments for additional risk mitigation treatments.

Incident response organisational structure, protocols and training

Many Australian water utilities have existing plans in place to deal with changing water quality and extreme weather events. In most cases, these plans were developed through an adherence to the ADWG Framework. In compliance with the ADWG, these utilities will have undertaken some form of "catchment to tap" risk assessment.

As part of the development and maintenance of risk management plans, incident response plans (IRPs) (sometimes called incident and emergency response plans) should be developed, with specific focus on the management of extreme circumstances. Specific issues that should be addressed in an IRP are identified in Box 1. Organisations should consider sharing their IRPs with other organisations that they will have to work with in the case of an emergency, so that each organisation is aware of how others plan to respond to incidents and emergencies. The IRP could be used as an input into developing broader interagency IRPs.

Box 1: Issues that should be addressed in an incident response plan (IRP)

- The circumstances under which an incident may be declared and the IRP would be applied
- Definitions of incident 'levels' (e.g., alert, minor, major) which may be declared and the clear implications that follow when an incident reaches each level.
- Composition of the incident management team structure responsible for coordinating implementation of the IRP.
- Provisions for rotating responsibilities in circumstances where 24-hour management may be required.
- Provisions for managing human resources, including overtime working arrangements
- Key decision makers for various operations and aspects of the plan
- A formal process for recording key decisions made during the incident (Who? What? Why?)
- Clear lines of command and communication
- Physical locations and specific means of communications for personnel (such as an Emergency Coordination Centre).
- Specific activities (such as increased water quality monitoring, changes to water treatment or storage) which may be triggered by the incident.
- Communication responsibilities, including communication within the organisation, communication with other organisations and communication with the media and the wider community.
- Up-to-date contact details for organisations and individuals to be contacted and consulted during the incident.
- The responsibility for major decisions and announcements, such as the initiation or cessation of a boil water alert.
- Circumstances under which an incident level would be downgraded or the incident would be considered to be have ended.
- A process for the regular review and update of the IRP

An IRP should identify the specific responses required from specific personnel within an organisation. However, since the consequences of extreme weather events can be hard to predict, water managers will need to be able to quickly adapt plans to changing circumstances. The development of IRPs should ensure that the most appropriate staff are identified to handle various scenarios.

An effective means of managing the necessary flexibility and the potential need for rapid decision making is to have identified a core incident management team. The incident management team would ideally be co-located and have access to all essential information as it becomes available.

The validity of assumptions embedded in IRPs must be carefully considered and periodically reviewed. Key assumptions for review include the likely impact of long duration loss of assets and the impact of supply disruption. Water quality managers should question the assumed level of redundancy that is built into water supply systems and whether the assumptions behind the redundancy remain valid. 'Mock simulations' (see "Inter-agency hypothetical scenario testing" section below) can be very useful tools to test the suitability of the IRPs.

Some organisations maintain a physical emergency coordination centre (ECC) as a dedicated space from which to coordinate the management of emergencies. Advantages of doing so may include:

- A known location for the emergency management team to quickly assemble.
- The EEC may be equipped with advanced communications facilities, including multiple telephones, cable internet, an uninterruptable power supply, and radio and satellite facilities.
- The EEC may be equipped with multiple televisions to monitor media reports.
- A known location for other agencies to quickly contact key emergency personnel.

Inter-agency relationships and networks

During an incident, such as an extreme weather event, there is often a need to coordinate planning and activities between multiple organisations. Organisations that may need to become involved include:

- Health regulators
- Environment regulators
- Catchment management organisations
- Bulk water suppliers and wholesalers
- Drinking water service providers (including neighbouring providers)
- Private water carters that access networks to provide water to off-grid customers
- Emergency services (e.g. State Emergency Service or SES)
- Firefighting organisations
- Police
- Media

It is essential that effective relationships between these organisations are established in advance of the need to manage incident situations. A register of contact details for key personnel should be maintained. The roles, responsibilities and relationships between agencies in responding to an incident should be clearly understood and documented.

Communication protocols between organisations should also be established and clearly defined. That is, personnel in areas that may be impacted by an event should know what their channels of communication will be during such an event.

Most States have existing multi-agency emergency systems. It is important that drinking water suppliers ensure that their requirements for responding to extreme events are recognised and incorporated within these established systems. Procedures for integrating IRPs with State plans need to be established.

Some Australian water utilities participate in a formalised mutual aid network, known as the Water Services Infrastructure Assurance Advisory Group. A key product of this Group has been the Australian Water Sector Mutual Aid Guidelines (WSIAAG & WSAA 2010). These Guidelines were developed to ensure that during times of disaster/emergency, water utilities are able to restore and sustain services more effectively by drawing on available resources from other unaffected areas in Australia. Implementing these Guidelines prior to a disaster/emergency should streamline the process of requesting, coordinating and deploying resources. This will save time in planning and administration, and in locating specialist personnel and equipment.

Inter-agency hypothetical scenario testing

Some utilities participate in multi-agency exercises in order to refine incident management plans, and confirm the compatibility and common understanding between agencies that may be involved in these sorts of incidents. Two hypothetical scenario exercises were developed and run as a means of identifying gaps in preparedness, as well as developing recommendations for this guidance document (Deere *et al.,* 2016).

Previous research has demonstrated that these types of preparedness exercises are effective in familiarising personnel with emergency plans, identifying gaps and shortcomings in emergency planning, and allowing different agencies to practice working together (Biddinger *et al.,* 2008).

Experience has demonstrated that hypothetical scenario exercises provide water utility personnel with a valuable opportunity to identify deficiencies while in a low-stress, noncritical environment (Whelton *et al.,* 2006). Solutions to these deficiencies can then be explored and implemented before an actual event occurs.

Hypothetical scenario exercises may be developed as structured discussions of evolving events or unstructured reactions to short scenarios. Facilitation may range from being minimally directive, allowing participants to assume responsibility for managing the discussion through "role play," to highly directive, enabling the facilitator to ensure that specific questions are addressed (Dausey *et al.,* 2007).

Although considerable variability is possible in the way that hypothetical scenario exercises are planned and executed, common elements typically include evolving hypothetical scenarios, facilitated group discussions, and some level of collective decision making by participants (Dausey *et al.,* 2007).

Hypothetical scenario exercises are considered to be particularly well suited to water system incidents since such events generally do not occur at a well-defined incident 'scene', but instead involve relatively abstract incident components, such as water contaminants (Moyer, 2005). It has been argued that while the participation of water utilities in these types of exercises is highly valuable, it is relatively uncommon and should be increased (Moyer, 2005; Whelton *et al.,* 2006). It is claimed that these exercises train utility personnel to make the critical decisions that may ultimately save lives and protect infrastructure (Whelton *et al.,* 2006).

Maintaining operations during and immediately following extreme weather events

Many extreme weather events occur with little or no prior warning. As such, it is essential that water managers are able to respond rapidly and effectively. With a high level of planning and preparedness, an initial response should be well rehearsed and close to automatic.

Enacting incident response plans and protocols

If an IRP exists it should be actively referred to during all incidents. The formalised plan should be adhered to as closely as possible.

In many cases, unforeseen circumstances or unanticipated complications will arise. These may render some aspects of the current IRP redundant or impossible to enact. In such cases, it will be necessary for the identified people with decision making responsibility to modify the plans and procedures accordingly.

An IRP could include a pro-forma system for recording key decisions that are made during an incident. Important information includes a description of the situation and the responses taken. Such records will be valuable for later retrospective analysis.

Effective event communication

A pre-defined communication plan is an essential component of any IRP. Ongoing communication, utilising all available channels, should underpin the response activities from water utilities and health authorities. Many extreme weather events are also associated with a loss of, or congestion of, many traditional communication channels. Increased website and call centre traffic, as well as a potential lack of electricity, must all be taken into account in such cases. In some circumstances, social media, which may be managed on hand-held devices from almost any location, can be an effective channel for disseminating public health and emergency warning messages. However, it should be recognised that not everyone has access to or uses social media.

Specific strategies and personnel should be identified to manage various forms of communications. These should include communication:

- between various departments, teams and individuals within the organisation.
- between organisations involved with managing the incident
- with a variety of media organisations
- with specific groups of customers who may require particular information
- with individual community members
- with whole communities, such as boil water alerts

Short-term risk management controls

In some circumstances, **emergency treatment capacity** may be mobilised. For example, the emergency use of powdered activated carbon (PAC) dosing capability to improve the treatment of organic substances, including natural organic matter and cyanotoxins, has been practiced (Khan *et al.,* 2016).

Careful management of **reservoir storages** during large flooding events can be used to control suspended matter and turbidity levels in the withdrawn water. Similarly, a variety of management options may be considered to better control water quality risks associated with cyanobacterial growth in water supply reservoirs. For example, hydrologic modifications, including enhanced vertical mixing, use of variable depth offtakes and, if water supplies permit, increased flushing (reducing residence time) may be effective in some systems.

Careful management of treated water already in the **distribution system** can maintain supply during the worst periods of extreme events. For example, some network supply reservoirs (water towers) may be more vulnerable to impacts than others and plans regarding supplying water to and from those reservoirs may be adjusted accordingly.

In response to growing water demands, some cities have begun **diversifying water sources** and management, using underground storage, water transfers, recycling, and desalination. These same tools are promising options for responding to some extreme weather events. For example, during major flooding in South East Queensland, severe water shortages were avoided by the use of a major water transfer system, known as the SEQ Water Grid (Khan *et al.,* 2016). In particular, the SEQ Water Grid was used to transfer water produced by seawater desalination to areas that would normally receive treated water from the Mid-Brisbane River. In this case, the use of the SEQ Water Grid to improve the resilience of the water supply system across SEQ was highly effective. Similarly, some small inland town supplies that routinely use surface water have bores that can be called upon during droughts or when floods make the surface water untreatable.

In addition to water quality impacts, extreme events may also severely affect **water quantity** by impeding the ability for water treatment plants to produce sufficient quantities of potable water, or for distribution systems to deliver sufficient volumes of water to customers. For example, events such as flooding and severe cold have resulted in the significant loss of mains water supplies in a number of European countries over recent years (Carmichael *et al.,* 2013).

Since water is important for sanitary purposes, maintaining water supply –even when water quality may be compromised- must be a high priority during extreme weather events. Supply should be maintained even if it is subject to a boil water or do not consume advisory. Furthermore, shortages have been documented to cause panic, despair, feelings of exposure, distress and helplessness among affected populations (Carmichael *et al.,* 2013).

The availability of back-up generator capacity may provide the capability to continue to treat and supply safe drinking water in cases where power distribution is impeded. Advanced modelling capabilities are increasingly available to assess the resilience of **current power supply systems** to extreme weather events, as well as forecast likelihoods and the extensiveness of power outages. Emerging modelling techniques may also be used to forecast the time to recovery from power outages.

In some cases, it may be necessary to provide **alternate drinking water supplies** to communities. Alternate water supplies can be delivered to affected communities via a number of routes, including tankers (static or bowser) and/or packaged water. However, these supplies need to be carefully dispatched and monitored in order to protect public health. During one UK flooding event, vandalism of tankers endangered public health and reduced the available stock (Carmichael *et al.,* 2013).

Short-term safe drinking water guideline values

Consideration of drinking water quality and the ability to meet the health-based and aesthetic guideline values in relevant drinking water guideline documents is required. Chemical guideline values are generally (but not always) based on chronic risk and a level of exposure that is regarded as tolerable throughout a lifetime, while pathogen guideline values are based on acute risks. This means that short-term spikes in microbial pathogen concentrations in treated water can increase pathogen risks considerably and lead to outbreaks of waterborne disease. On the other hand, limited, short-term exceedance of chemical guideline values does not necessarily mean that the water is unsafe for consumption, provided that the average intake of elevated concentrations of particular chemical(s) over longer periods of time does not exceed the acceptable daily intake. This is particularly true for some disinfection by-products, for example, which may exceed current guideline values as a result of high-dose disinfection to maintain pathogen control in extreme weather event situations. However, consideration should also be given to any potential acute effects on a chemical-by-chemical basis.

Any exceedance must be reported to health authorities, but some guidance is provided below on calculating safe short-term chemical guideline values for various chemicals for decision making process in emergency situations (Box 2). Various 1-day and 7-day Short Term chemical Exposure Trigger Values (STETV) were calculated for chemicals that may be relevant in extreme weather events (Table 2) (Leusch *et al.,* 2016).

Table 2 Short Term chemical Exposure Trigger Values (STEV) (Leusch *et al*., 2016)

Chemical	**Class**	**ADWG GV (µg/L)**	**1d STETV (µg/L)**	**7d STETV (µg/L)**
Total THMs	Disinfection by-product	250	3,000	1,000
Chloroform	Disinfection by-product	na [a]	3,000	3,000
BDCM	Disinfection by-product	na [a]	2,000	1,000
DBCM	Disinfection by-product	na [a]	5,000	3,000
Bromoform	Disinfection by-product	na [a]	5,000	3,000
Microcystin	Algal toxin	1.3	10	10
Cylindrospermopsin	Algal toxin	1 [b]	10	10
Saxitoxin	Algal toxin	3 [b]	3	3
Glyphosate	Herbicide	1,000	100,000	50,000
Atrazine	Herbicide	20	2,000	900
Simazine	Herbicide	20	2,000	900
Diuron	Herbicide	20	200	100
2,4-D	Herbicide	30	4,000	2,000
Methylparathion	Insecticide	0.7	70	40
Chlorpyrifos	Insecticide	10	100	50
Dimethoate	Insecticide	7	70	40
Diazinon	Insecticide	4	40	20

Notes: (a) The ADWG does not provide guideline values for individual THMs, instead providing a value for total THMs.
(b) Not a guideline value, but a health alert value.

Box 2: Calculation of a Short-Term Exposure Trigger Value (STETV).

Various approaches were compared to derive safe short-term exposure guideline values for chemicals (see Leusch et al. 2016 for full details), including:

- Using the acute reference dose (ARfD) combined with an allocation factor of 100% for 1d and 50% for 7d (as proposed in section 8.7.5 of the World Health Organisation Guidelines for Drinking-water Quality; WHO 2011);
- Multiplying the current ADWG guideline value if it is based on a chronic effect from lifetime exposure (i.e., NOT if it is based on an acute effect) by 10× and combining with an allocation factor of 100% for 1d and 50% for 7d; and
- Plotting the no-observable adverse effect level (NOAEL) of all available animal and human toxicity data against the logarithm of the exposure duration, and fitting a log-linear regression to the most sensitive species (or human data, if available) to directly extrapolate the 1d and 7d NOAEL.

The three methods produced comparable results, generally within an order of magnitude, and often overlapping the UKWIR Short-term No Adverse Response Level (SNARL) and the USEPA Health Advisories (HA) levels where those were available. Simply adjusting the guideline value using a standard extrapolation factor of 10× and the allocation factor (approach 2) often produced a highly conservative value. This simple approach may be suitable to quickly determine reasonable short-term guideline values for chemicals meeting the criteria noted above in preparing for an emergency situation. It is important to carefully consider the basis for the current ADWG guideline value (as provided in the ADWG factsheets) to understand whether this approach is suitable for a particular chemical.

Example calculation 1 – Glyphosate: The current ADWG of 1,050 ug/L is based on toxicity data from lifetime exposure and uses an allocation factor of 10%. Multiplying the guidelines value by a factor of 10× and adjusting the allocation factor to 100% and 50% would yield a 1d STETV of 100,000 μg/L and a 7d STETV of 50,000 μg/L, respectively.

Example calculation 2 – Total THM: The current ADWG of 250 μg/L is based on a 90-d rat study with an allocation factor of 10%. As the guideline is based on an assumption that the outcome would be unchanged from a lifetime exposure, it is inappropriate to apply the 10× extrapolation factor for conversion from chronic to acute exposure, but it is possible to increase the allocation factor for short-term exposures. Using 100% and 50% allocation factors would yield a 1d STETV of 3,000 μg/L and a 7d STETV of 1,000 μg/L, respectively.

Example calculation 3 – Microcystin: The current ADWG of 1.3 μg/L is based on a short-term 13-week study with an allocation of 90%. The current guideline value is not based on toxicity data from lifetime exposure (but rather a 13-week study), and already used a high allocation factor (90%). However, the guideline does include a 10× uncertainty factor to account for the short duration of the study and possible carcinogenicity, and this uncertainty factor can therefore be removed for calculation of a short-term value. Thus, a 1d and 7d STETV (with unchanged 90% allocation) would be 10 μg/L.

After the event

After the management of an extreme weather event has concluded, a number of post-event activities will be appropriate. These include efforts to implement full recovery to normal operations and activities to capture key learnings from the experiences.

Event recovery

Following many incidents, personnel and time will be required to recover operations to normal circumstances. Short-term emergency treatment solutions may need to be gradually removed. Similarly, changes to catchment management protocols, such as temporary water supply or storage solutions may need to be reversed. In situations where catchments have been damaged (e.g., following bushfires or cyclones), recovery may be a long-term procedure requiring dedicated staff and attention for a period of time stretching into months. Appropriate resources will need to be allocated to manage this response.

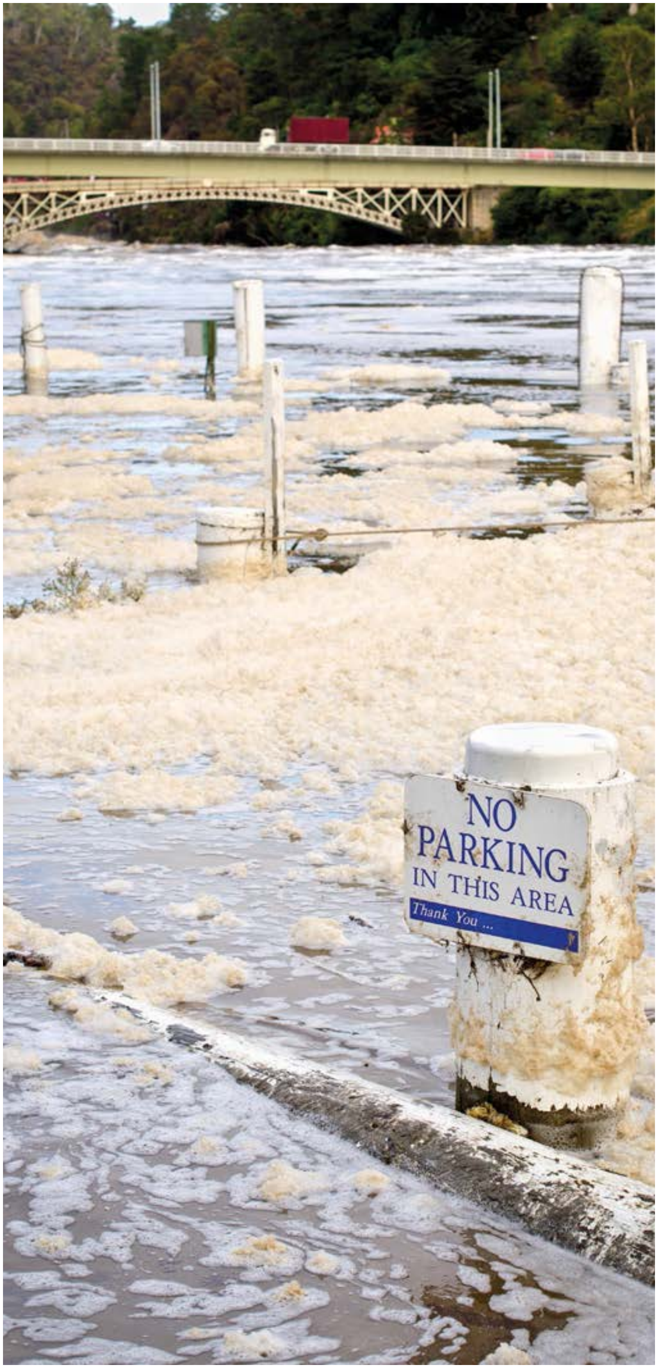
Learning from experiences

Post-event refinement of plans is an important part of the post-event process to ensure optimum future preparation. Practices for reviewing such plans should involve multiple people in the learning process, including staff and other stakeholders.

Following a major event, a high level of exhaustion can occur within an organisation. Furthermore, many routine activities may have been delayed or postponed in order to focus efforts on managing the event. These circumstances may result in a failure to conduct a 'hot debrief' immediately following an event. However, such a debrief is essential since it offers opportunities to capture learnings while they remain fresh. Thorough debriefing should take place as soon after an event as is practical.

A systematic process should be used to review the causes of successes, failures and near misses to learn useful lessons for the organisation. Generally, post event analysis will seek to illuminate the following (Standards Australia & Standards New Zealand, 2013):

- Whether the risks involved were properly understood?
- Whether people acted as anticipated or assumed?
- Whether the prevailing conditions were as assumed?
- Whether the controls operated as had been assumed or intended?
- Whether monitoring and review processes were effective?
- What remedial or improvement actions are required, who should implement them and by when?
- How any lessons that arose for the event should be 'learnt' and codified by the organisation?



Post-event debriefs should capture an understanding of how the event was managed, including aspects that worked according to plan and aspects of plans that failed. Key decisions (who made the decision? when? why?) should be fully documented and reviewed. The process should include the following (Standards Australia & Standards New Zealand, 2013):

- Establishing and recording the exact purposes of the review and the methods to be used.
- Communicating the purpose.
- Collecting and preserving evidence.
- Accurately recording the observations and recollections of witnesses.
- Creating accurate time-lines of occurrences.
- Initiating any supplementary studies to obtain additional information.
- Conducting analyses to determine the root causes of any successes or failures.
- Preparing draft findings.
- Identifying possible improvement actions.
- Seeking comments.
- Finalising the report.
- Implementing improvements.

Knowledge dissemination

Knowledge gained by experiences in managing extreme weather events should be shared with other relevant organisations. There are a variety of means by which this knowledge can be disseminated. These may include the following:

- Development of an incident report, which may be made available to other organisations or placed on an organisation's website.
- Presentation of key learnings at appropriate industry conferences.
- Focused workshops with key organisations to share leanings.

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