Severe Weather Impact Prediction Sector Partner Engagement

Final Report

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We acknowledge the Traditional Custodians across all the lands on which we live and work, and we pay our respects to Elders both past, present and emerging. We recognise that these lands and waters have always been places of teaching, research and learning.

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We would like to acknowledge the Traditional Owners of the lands on which we meet and work throughout Australia. We pay our respects to their Elders past, present and emerging and acknowledge that sovereignty was never ceded.

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We also thank all the sector partners who participated in our end-user surveys and workshops. All participants provided incredibly valuable insights and unique perspectives from their roles in their respective organisations. Their thoughtful and nuanced feedback provided us with the contextual richness that underpin the insights in this report.

Special thanks to Natural Hazards Research Australia, especially Kat Haynes and George Goddard, for their ongoing support throughout the project.

Acronyms and terms used in this report

Acronym or term	Description
AEIP	Australian Exposure Information Platform
AFAC	Australasian Fire and Emergency Service Authorities Council
AGOL	ArcGIS Online (see term below)
AIIMS	Australasian Inter-service Incident Management System
ArcGIS Online	Geoscience Australia's online mapping and geographic information analysis technology solution
BNHCRC	Bushire and Natural Hazard Cooperative Research Centre
Bureau	Bureau of Meteorology
EM	Emergency Management
FSWISTG	Flood and Severe Weather Intelligence Services Technical Group
GA	Geoscience Australia
H	High-level (Implication reference)
IMT	Incident Management Team
JTWC	Joint Typhoon Warning Centre
LEMC	Local Emergency Management Coordinator
LSW	Large scale wind
NEMA	National Emergency Management Agency
NHIRS	National Hazard Impact and Risk Service
NHRA	Natural Hazards Research Australia
NSW	New South Wales
NWP	Numerical Weather Prediction
SES	State Emergency Service
SME	Subject Matter Expert
STC	Scientific and Technical Capability (Implication reference)
STS	Severe thunderstorm
WMO	World Meteorological Organisation

Executive summary

Impact forecasting is a relatively new field of modelling and is still very much in its infancy in Australia and internationally. In Australia, the Bureau of Meteorology (the Bureau) supports a mature weather forecasting capability, while Geoscience Australia (GA) maintains mature exposure information datasets, and a growing suite of vulnerability models for residential housing assets, in particular. While still an emerging field of study, further research, and investment in developing impact-based modelling capability could have the potential to provide significant benefits for emergency management sector partners in preparing for and responding to disasters.

Collaborative Consulting Co, alongside the Bureau and GA, engaged with emergency management organisations and industry stakeholders (referred to collectively as 'sector partners' in this report) to understand the sector's needs for advancing severe weather impact forecasting capabilities. This includes understanding how existing and potential capabilities within the Bureau, GA and other industry providers can be adapted and enhanced to meet those needs.

This project set out to explore the potential utility of exposure and impact forecasting for severe weather, specifically severe thunderstorms and large-scale winds. The project sought to understand the exposure and impact information that emergency management sector partners and industry stakeholders require to better support their decision making in preparing for and responding to severe weather to mitigate the impact for communities.

In this report 'exposure forecasting' refers to the prediction of those assets in the path of a weather event. 'Impact forecasting' refers to the predicted amount of damage that will be sustained by physical assets in the path of an event.

Throughout this project, many sector partners indicated that as exposure and impact forecasting is still a new concept, they are yet to fully turn their minds to impact forecasting information to support decision making during severe thunderstorms and large-scale wind events. However, the sector indicated significant interest and appetite to better understand exposure and impact-based forecasting generally and how it can be used to better support decision making across all hazards. Generating and presenting hazard, exposure and impact ensembles will require sector partner education and appropriate reinforcement of the distinction between the concepts to support the appropriate decision-making response.

While still a new concept, this project acknowledges that predicting impact is not new for sector partners. On a qualitative level, for example, the Bureau has a long history of providing severe weather warnings that include statements concerning the potential for damage associated with wind gusts.[1] Response agencies currently do this by bringing together their experience and local knowledge, while communicating comprehensively with colleagues on the ground, other sector partners and referencing various information sources before and during an event. For example, when a severe weather event is forecast for an area, response agencies can anticipate potential impacts on homes, roads and buildings and continually validate anticipated impacts information through sources available to them.

Impact forecasting, both in Australia and internationally, is currently drawing more from lived experience than analysis of automated data-feeds, although there is growing maturity in the tropical cyclone domain. The Bureau and GA have considerable expertise and capability that they are already bringing to this area, as exemplified by the existing National Hazard and Impact Risk Service (NHIRS). These capabilities, applied in an appropriately targeted fashion, will support the sector in moving exposure and impact forecasting from a qualitative level to an increasingly quantitative level. The future of impact forecasting in Australia involves further developing and expanding this capability and collaborating strongly with the emergency management sector to bring together experience, local knowledge, and advanced technical expertise in accessible, easy to digest formats that are time effective and appropriately support decision making.

The insights from sector partners collected and presented in this Report will help steer further research projects that will be of most benefit for emergency response agencies, acknowledging there is strong interest in exposure and impact forecasting from a wide range of sector partners and industry stakeholders. Bringing sector partners and industry

[1] http://www.bom.gov.au/weather-services/severe-weather-knowledge-centre/sample-stsw-sa.shtml

stakeholders together on future projects would ensure we maintain momentum beyond this project in building impact forecasting capability across the sector.

Summary of Implications

Following analysis of sector partner contributions, eight key information decision-making information needs were validated with the national reference group, and eight key findings identified. These findings support a combination of high-level, scientific, and technical capability Implications. Further details around the Implications are contained within the body of the report.

High-level Implications:

1. Timely access to a range of appropriately presented information, spanning meteorological, exposure and impact forecasts would support real-time decision-making for EM sector partners. To achieve this goal, continue collaborating with the EM sector to build awareness of exposure and impact forecasting, and better understand the sector's operational needs.
2. Extend scientific and technical capability in line with sector partner information needs (as highlighted below in scientific and technical capability implications).
3. Consider a phased approach to providing enhanced information for decision-making, focusing initially on exposure forecasting, followed by impact forecasting.

Scientific and technical capability implications for the Bureau and GA and/or other providers to consider:

1. Expand on the meteorological features and functionality provided by the Bureau to include:
    - i. Antecedent environmental conditions relevant to EM sector partners.
    - ii. Information on the relative intensity and atypicality of forecast conditions for effected localities.
    - iii. Information on the range of conditions (from most likely to reasonable worst case) that may be expected during an event, for example, detailed information from ensemble forecasts.
    - iv. Information on relevant historical meteorological events that might assist EM sector partners in planning response activities.
2. Expand on the features and functionality contained within Bureau and/or GA's information products to include:
    - i. Real-time verification indicating accuracy of most current forecasts against observations.
    - ii. Ensemble exposure and impact forecasting capability.
    - iii. Identification, quantification and location of vulnerable cohorts, including but not limited to aged care centres, schools, mass gatherings and transient communities.
    - iv. Identification and location of community buildings and critical infrastructure, and where possible, the development of applicable vulnerability models for those assets.
    - v. Development of proxy indicators for exposure and impact, with the methodology to be validated with sector partners.
    - vi. A longer-term research question should explore the link between forecasts of physical impact and subsequent social impacts, with a view to rapid estimation of impacts informing response, early relief and recovery decision-making.
3. Develop and implement a communication and engagement approach with sector partners to support the communication and interpretation of detailed technical information in accessible formats during an incident, including:
    - i. Data provided by the Bureau, GA and/or other providers, and any limitations of the models underpinning the outputs.
    - ii. Methods for communicating uncertainty and/or the limitations of meteorological, exposure and impact forecast information products.
    - iii. Methods for consolidating, synthesising and simplifying the presentation of information from a range of sources, including, for example, connection of services in ArcGIS Online (AGOL) or similar platforms.
    - iv. Appropriate materials designed to raise user awareness and support the understanding of terminology, interpretation of forecast data, and understanding of potential limitations of data sets and models.

End-user statement

Steve Muncaster, Victorian Head Office, Victorian State Emergency Service (VICSES)

VICSES greatly values the insights provided by the Severe Weather Impact Prediction report. As a hazard intelligence analyst, I can attest to the critical importance of timely access to severe weather impact forecasting information. This research not only enhances our ability to make informed decisions regarding operational response but also aids in effectively planning for relief and recovery efforts in the face of severe weather events.

The collaboration between AFAC Flood and Severe Weather Intelligence Services Technical Group (FSWISTG) and the research team enabled access to various views and requirements across all jurisdictions. This project facilitated improved coordination and consultation between response agencies and the Bureau.

I commend the team's efforts in enhancing communication between stakeholders in the emergency management sector. This collaborative effort has undoubtedly strengthened our ability to mitigate the impact of severe weather events on our communities.

Introduction

Collaborative Consulting Co, alongside the Bureau and GA, engaged with emergency management organisations and industry stakeholders (referred to collectively as 'sector partners') to understand the sector's needs for advancing severe weather impact forecasting capabilities. This includes understanding how existing and potential capabilities within the Bureau, GA and/or other industry providers can be adapted and enhanced to meet those needs.

In this context, severe weather refers to large-scale winds and severe thunderstorm events. Sector partners primarily refers to decision-makers during the planning, preparedness, or response phase of a severe weather event from organisations with statutory obligations for emergency response and to mitigate the impacts of severe weather for communities. Sector partners includes the meteorologists from the Bureau who are embedded within these organisations.

Engagement with sector partners focused on information needs regarding the exposure of assets (i.e., those assets in the path of a weather event) and impact (that is, the amount of damage predicted to be sustained by physical assets in the path of an event). Exploring compounding hazards and cascading effects, for example, flooding or landslips that result from severe weather events, was beyond the scope of this project.

Background

The predictive capability for severe weather forecasting, and hazard forecasting more generally, is increasingly moving from a purely hazard-based service to providing information about the resultant impact. In 2015, the World Meteorological Organisation (WMO) summarised this direction as the desire to understand not only 'what the weather will be', but 'what the weather will do'. Such impact-based forecasting, however, exists on a complex spectrum, and the information required to understand 'what the weather will do' depends on the user. For example, a community member may wish to understand how their individual property will be impacted by a severe weather event, while an emergency manager may need an informed understanding of the aggregated exposure and damage expected to ensure resources are available to respond over a broad area for an extended time period.

For the purposes of this report, impact describes a wide range of consequences from a hazard including physical damage to buildings and property, and disruption to services. The impact of a hazard can be understood as the intersection of the likelihood of the hazard, and the vulnerability and exposure of an individual, community, or asset to that hazard. *Figure 1. The Impact Triangle*, below, highlights the information sources available from the Bureau and Geoscience Australia.

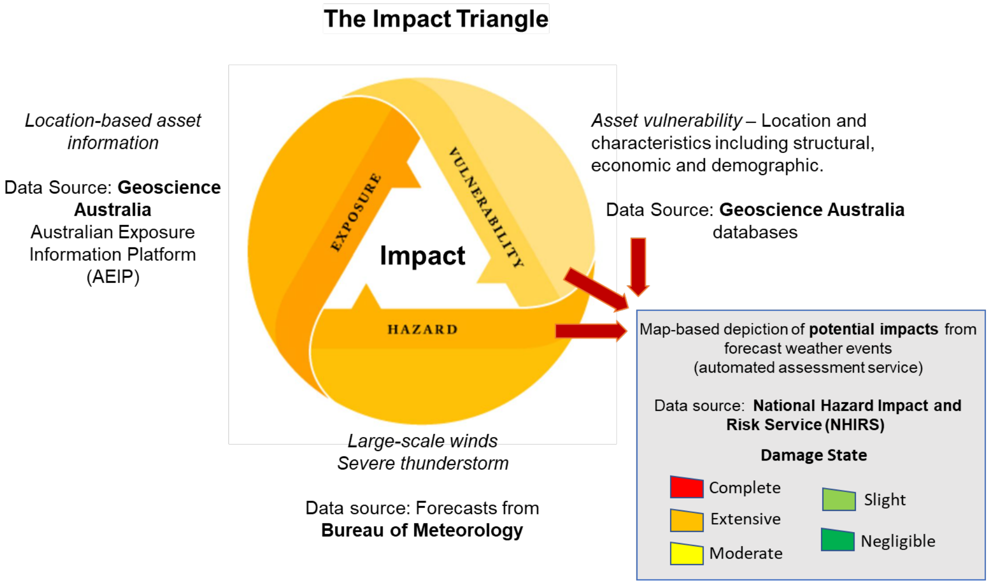

FIGURE 1. THE IMPACT TRIANGLE

The impact triangle[2] considers information regarding the hazard, exposure, and vulnerability:

- Hazard - large-scale winds and severe thunderstorms forecast from the Bureau;
- Exposure - using location-based asset information provided by Geoscience Australia in the Australian Exposure Information Platform (AEIP); and
- Vulnerability - Asset vulnerability, including the location and structural, economic, and demographic characteristics.

In its simplest form, the actions taken from a hazard forecast can be informed by potential impact, with warnings or alerts issued based on thresholds known to have correlation with significant outcomes. A rudimentary example is the current Severe Weather Warning issued by the Bureau, which for much of Australia is triggered for severe wind gusts exceeding a static threshold of approximately 90 km/h. This approach is reasonable but requires the user to further contextualise the impact based on their own perception of what is exposed and how vulnerable exposed assets are to the hazard. An emergency manager may identify that a severe weather event impacting an area of low population, or a town with a high proportion of modern buildings, is less likely to require significant resources than a heavily populated area with less resilient infrastructure, for example. A more sophisticated forecast, therefore, would combine the hazard prediction with detailed information about the assets or communities exposed in the event. The most advanced impact forecasting methods would use detailed vulnerability information describing how all exposed assets will respond to the hazard, to explicitly quantify what damage or disruption the weather will cause. We note that in the event of major disasters, the insurance industry has equivalent systems that are driven by financial consequences and are not intended to be used to inform EM response.[3]

With much of the severe weather predictive capability still in the hazard-forecast space, impact-based forecasting in Australia is relatively youthful. Recently, the skill and utility of these hazard forecasts has improved significantly. For example, high-resolution Numerical Weather Prediction (NWP) ensembles can now provide reasonably reliable probabilistic guidance on the likelihood of severe weather, including severe thunderstorms. Furthermore, radar systems

[2] The concept of the Impact Triangle reflects the Risk Triangle as applied by the Emergency Management sector. In this context, where the risk is certain (that is, likelihood approaches 1.0), risk equates to impact.
[3] https://www.zurich.com/en/commercial-insurance/sustainability-and-insights/commercial-insurance-risk-insights/rapid-damage-assessment-tools-demonstrate-value-in-turkish-earthquake

can be used to support short-term predictions (called 'nowcasts') of severe thunderstorms, as well as high-quality analysis of the location and intensity of recent severe weather.

What is not being fully realised, however, is the power of incorporating available exposure data (building locations and types, broader infrastructure information, demographic information and so on) and available vulnerability information to add value to the hazard forecasts (temporal, spatial and intensity).

Overlaying exposure and vulnerability information contextualises the risk to the community of a forecast hazard and bridges the gap to impact-based forecasting and post-event appraisal.

There is a clear opportunity to provide more detailed and tailored information to emergency management agencies, which will better inform preparedness and response activities to save lives and reduce damage to properties.

The Bureau and GA recently collaborated on a Bushfire and Natural Hazards Cooperative Research Centre (BNHCRC) project to better understand the value of impact-based forecasting. This project, titled 'Impact-based forecasting for the coastal zone: East Coast Lows' (2017-2020), explored the concept of integrating hazard forecasts with exposure datasets and vulnerability models to predict impacts of severe weather. That project revealed the complexity of drivers of damage - direct wind impacts, debris, water ingress and flooding all contributed to and compounded the damage observed from an East Coast Low. The project demonstrated the feasibility of connecting the Bureau’s high-resolution NWP output with exposure data and vulnerability models for the purpose of estimating impact, an approach which was ultimately used to estimate the damage caused by severe wind on residential housing.

A follow-up utilisation project, led by GA, implemented this as an automated system, running the operational weather forecast models through the impact modelling framework to derive modelled predictive impact data in near-real time. That project served as a proof-of-concept and provided emergency management agencies with (up to) 36-hour lead time on predicted impacts of imminent severe wind events on residential structures.

Aims and rationale

The project’s aim was to undertake an engagement process that elicited the information requirements of the emergency management sector when making decisions before and during a forecast severe weather event, and to understand how existing impact prediction capability should be developed and the types of information required by different user groups.

While the Bureau and GA have collaborated with sector partners to understand how impact prediction information can inform operational decision-making, this research project provided the opportunity to explore the current national picture as well as inform the future development path for impact-based forecasting products and services.

When forearmed with forecast impact and exposure information regarding predicted large-scale winds (LSW) or severe thunderstorm (STS) events, emergency management agencies may have a greater ability to mitigate adverse impacts and better inform, prepare, and protect the community. This may be through better public information and warnings, timely securing of structures, safe evacuation, or the appropriate pre-positioning of resources, including evacuation or relief centres, to minimise disruption to community.

Achieving these outcomes requires strong collaboration and trust between the information providers, such as the Bureau and GA, and emergency management agencies. The outcomes of this research will contribute to strengthening the capability to provide clear fit for purpose information, which in turn will build agency confidence in using impact information to improve community resilience to severe weather events.

Project approach

The project approach was designed to provide practical guidance for the Bureau, GA and/or other industry providers to improve and further develop prediction modelling and diagnostic capabilities. This involved identifying key sector partner 'user types', the most common 'use cases' or decision-making scenarios and, from those use cases, identifying the information needs for severe weather impact forecasting.

Extensive engagement was undertaken with sector partners to understand the perspectives of all Australian jurisdictions and various decision-making roles within the planning, preparedness, and response phases of an event.

The Australasian Fire and Emergency Service Authorities Council (AFAC) Flood and Severe Weather Intelligence Services Technical Group (FSWISTG) provided project guidance as the Project Reference Group. FSWISTG has multi-jurisdictional representation and were engaged at key project points:

- design of the project parameters and to identify use cases (decision-making scenarios);
- facilitate project engagement with sector partner decision-makers from own agencies and professional networks; and
- validate project findings and provide additional context.

Key sector partner engagement opportunities included:

- An introductory workshop at the Natural Hazards Research Australia Research Forum, Melbourne, May 2023;
- A publicly available online survey promoted by Natural Hazards Research Australia and the FSWISTG members to those with an interest in the potential use and development of exposure impact forecasting. The survey received 166 survey responses.[4] Refer to Appendices 2 and 3 for survey design and survey outputs;
- In-depth analysis using two complex scenario-based workshops involving severe wind and thunderstorms.[5] Scenario-based workshops involved participants from across Australia from within the emergency management sector and included local government emergency management coordinators, power and water utility representatives, telecommunications carriers, a national supermarket chain and outdoor education providers. See Appendix 3. for workshop outputs;
- Targeted consultation with a number of key stakeholders:
    - AFAC Community Engagement Technical Group
    - AFAC State Emergency Service (SES) Community Safety Group
    - Manager Operational Improvement and Lessons, NSW State Emergency Service
    - National Situation Room, National Emergency Management Agency; and
- A presentation and follow-on discussions at *Pitchfest: There's a storm brewing*, to sector partners attending the innovation stream, AFAC Conference, Brisbane, August 2023.

[4] Online survey was conducted using surveymonkey.com. 166 responses were received between 18/06/2023 and 22/07/2023.
[5] Two online scenario-based workshops attracting 48 registered participants were conducted using miro.com on 17/08/2023 and Friday 18/08/2023.

Sector partner context

Three key user types and ten use cases drive sector partner needs

Through engaging with emergency management organisations and industry stakeholders (collectively 'sector partners'), three key types of decision-makers (user types) and ten key decision-making scenarios (use cases) were identified. These user types and use cases provide the structure for analysing and presenting the findings and implications.

Types of decision-makers

1. Emergency management agency decision-makers in the **intelligence function** of an **Incident Management Team** (following the Australasian Inter-service Incident Management System (AIIMS) structure) in the **Response phase**[6]. The Intelligence function is responsible for:[7]
    a. Situation and Analysis – Collection, analysis and organisation of situation information and data, including maintaining the Common Operating Picture;
    b. Modelling and Predictions – Uses knowledge of the current situation and modelling tools to predict the incident behaviour to support the options analysis part of planning;
    c. Technical advice – Provides expert technical advice; and
    d. Mapping – Mapping information and supporting documents summarising and describing the incident.
2. **Relief and recovery functions**[8] in local, State and Commonwealth agencies:
    a. Emergency relief can be provided in a variety of settings including relief centres, community facilities and directly to communities or individuals who may be isolated or sheltering in place; and
    b. Recovery services support emergency-affected persons in the reconstruction of the physical infrastructure and restoration of emotional, social, economic, and physical wellbeing (e.g. Australian Red Cross).
3. **Essential services and critical infrastructure providers**. While there is no consistent definition of essential services across Australian jurisdictions, they may generally considered to provide services without which the safety, health or welfare of the community or a section of the community would be endangered or seriously prejudiced.[9] These can include production, supply and distribution of energy, supply and distribution of water, public transportation of people or freight, roads, telecommunications, sewerage infrastructure, fire-fighting services, hospitals and education.

Additional user types emerged through the research engagement process that are interested in exposure and impact information including outdoor activities groups and policy and longer-term planning functions within all levels of government and other organisations. Examples of outdoor activities groups include tourism operators and outdoor education groups, who implicitly or explicitly have a level of responsibility for the safety of groups of people in their charge that may be exposed to an emergency event. Policy and longer-term planning functions[10] within all levels of

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[6] Emergency Management Victoria (EMV) defines the roles and responsibilities in the response phase 'Response phase of an incident comprises actions taken immediately before, during and in the first period after an emergency to reduce the effects and consequences of the emergency on people, their livelihoods, wellbeing and property.'
[7] EMV, Intelligence and Information Sharing core capability. https://www.emv.vic.gov.au/responsibilities/state-emergency-management-plan-semp/roles-and-responsibilities/agency-roles-and-responsibilities-alignment-to-victorian-preparedness-framework/intelligence-and-information-sharing
[8] Inspector General for Emergency Management, Victoria, defines 'Emergency relief' as the delivery of assistance to meet the basic and essential needs of individuals, families and communities during and in the immediate aftermath of an emergency; and 'Recovery' as those programs that go beyond immediate relief to assist affected people to rebuild their homes, lives and services and to strengthen their capacity to cope with future disasters.
[9] Essential Services Act 1981 (SA) provides a useful definition.
[10] Emergency Management Victoria roles and responsibilities for the Planning Phase.

government, including land use planning, as well as essential services and critical infrastructure providers who require impact-based forecasting information to forward plan weeks, months and years ahead.

While these additional user types have an interest in exposure and impact forecasting information, their perspectives and roles differ. Outdoor activities groups are generally responsible for the immediate safety of a relatively small number of people and, based on the feedback we received, have decision-making processes that have limited capacity to incorporate significant uncertainty in impact forecasts. Policy and planning functions are informed by events that take place and extreme event scenarios, but do not use impact information while an event takes place. We have therefore excluded these user types in our analysis below and at *Table 1.*

Decision-making scenarios

While there are many important functions undertaken during incidents at various stages, ten key use cases (decision-making scenarios) were identified that could make significant use of exposure and impact forecasts. These use cases include:

1. **Activating emergency response teams** - includes establishment of Incident Management Teams (IMTs) and initiating a Local Emergency Management Coordinator (LEMC) where appropriate. These personnel are responsible for the functions of operations, planning, and logistics during an incident.

2. **Resourcing allocation and rostering response teams** - includes potential pre-positioning of physical and human resources prior to the onset of an incident, as well as the on-going assignment and rostering of personnel and equipment during the incident. This use case is undertaken through the IMT.

3. **Communicating ongoing risks and impacts to government, stakeholders and the community** - includes the provision of information to sector partners in a form and level of detail suitable to support decision making prior to and during an incident, as well as to inform early relief and recovery efforts. Note that this communication is separate to the specialised provision of information and warnings to the public but does inform personnel responsible for issuing such warnings.

4. **Issuing information and warnings** - includes information to the public through various channels, including emergency alerts and social media, in a form that is considered most meaningful to the general public.

5. **Coordinating with other agencies, essential services and critical infrastructure providers** - includes coordination between all key stakeholders involved in responding to an incident, providing information supporting response / relief and recovery activities, and ensuring any actual or potential essential services and critical infrastructure issues are being addressed by the relevant authorities.

6. **Identifying and establishing evacuation centres and routes** - includes ensuring that sufficient and accessible evacuation centre capacity exists and is appropriately resourced.

7. **Planning and setting up relief centres, providing accommodation and logistics co-ordination** - includes assessing the numbers of people that will need to be evacuated and/or be displaced from homes, the facilities (and their accessibility) available to accommodate those people, and the co-ordination of support requirements (for example, food, bedding, clothing and so on).

8. **Assessing damage/length of disruption to homes, critical infrastructure, community facilities and access routes**. This is focussed on early estimation of the severity of the event, covering location and extent of damage to critical infrastructure, facilities required and available to support response and relief efforts, and time to restoration of services and critical infrastructure.

9. **Planning to support vulnerable cohorts** - includes, and is not limited to, identifying potential impacts on aged care facilities, homeless persons, culturally and linguistically diverse groups, travellers and large public events. The subsequent focus is on identifying the response and relief activities that may be required to assist those groups.

10. **Planning for the recovery phase** - includes information and co-ordination across all levels of governments, organisations involved in recovery, and the business sector. With respect to government, in various forms, this includes responsible ministers, elected members and government departments, all seeking early and reasonable information on the scale of events so as to inform a range of options, from activating the Australian Defence Forces through to activating National Disaster Relief and Recovery Arrangements. For organisations involved in recovery, this spans establishing management teams and deploying and rostering resources to assist in physical and mental aspects of disaster recovery. For businesses, this includes, for example, understanding the impact of human, physical infrastructure, and critical infrastructure issues on business continuity.

Table 1 shows the alignment of the key user types and key use cases:

Type of decision-maker / Decision-making scenario	Response function	Relief/ Recovery function	Essential services and critical infrastructure
1. Activating emergency response teams, including the IMT and LEMC	X		X
2. Resourcing allocation and rostering response teams	X		X
3. Issuing information and warnings to the public through various channels, including emergency alerts and social media	X		
4. Coordinating with other agencies, essential services and critical infrastructure providers	X		X
5. Communicating ongoing risks and impacts to government, stakeholders and the community	X	X	X
6. Identifying and establishing evacuation centres and access routes	X	X	X
7. Planning and setting up relief centres, providing accommodation and logistics coordination	X	X	
8. Assessing damage/length of disruption to critical infrastructure, homes, community facilities and access routes	X	X	X
9. Planning to support vulnerable cohorts (aged care, health services, education)	X	X	X
10. Planning for the recovery phase		X	X

TABLE 1. LINKAGE BETWEEN TYPE OF DECISION-MAKER AND KEY DECISION-MAKING SCENARIO

Key findings

Finding 1: Strong multi-jurisdictional interest from a wide range of sector partners and industry stakeholders can drive the future development of exposure and impact forecasting capabilities

The project received strong interest from a wide range of sector partners, including industry stakeholders. It was originally anticipated that impact-based forecasting would primarily support sector partners, who we have defined as decision-makers during the planning, preparedness, or response phases of an event from emergency management organisations, including meteorologists from the Bureau embedded within these organisations.

Our research found that there was appetite from stakeholders beyond just sector partners. In addition to sector partners, other key stakeholders are interested in and would value impact-based information to support their decision making before, during and after a disaster. These stakeholders include essential services providers such as utilities providers, food supply chain, and insurance representatives.

In an environment where we have had compounding and cascading disaster events, sector partners and industry stakeholders prioritised their time to participate in this research project. This reflects the strong interest in impact-based forecasting and further developing this capability in Australia.

For a food supply chain partner, impact forecast information would support decisions related to the movement of critical goods, store openings and closures, and restrictions on transport.[11] For a utilities company, decisions related to asset protection, resilience and preparedness could be supported by impact-based forecast information.[12] For a school, this information would support decisions to make changes to school programs (such as outdoor camps and expeditions), and support broader risk preparedness and seasonal planning.[13]

There was also interest from the Commonwealth, namely from the National Emergency Management Agency (NEMA). NEMA is developing a Common Operating Picture for sharing of information with other agencies during emergency events. We heard from NEMA that there is a desire for impact information to help inform resourcing decisions at a national level.

For NEMA, impact forecast information would ensure they have a deeper appreciation of the impact of the hazard and better understand required resources and locations for those resources from a strategic perspective. Additionally, it would also allow for consideration of potential recovery assistance in the short to medium term.[14]

There is appetite from these stakeholders to further collaborate on a range of meteorological, hazard, exposure and impact-based forecasting products. As impact forecasting is still maturing, mapping exposure is more likely to appeal to sector partners and industry stakeholders in the short term.

[11] Respondent #118, Severe Weather Impact Prediction Sector Partner Survey ('Sector Partner Survey')
[12] Respondent #9, Sector Partner Survey.
[13] Respondent #26, Sector Partner Survey.
[14] Respondent #3, Sector Partner Survey.

Implication:

- Engage with the cross-section of sector partners who have registered interest through this research initiative to contribute to the development roadmaps of the Bureau, GA and/or other industry providers. This may include further requirement gathering activities, user testing of tools or development of other functionality. See **Implication H2.1**

Finding 2: Significant appetite exists for obtaining intelligence beyond current meteorological forecasts to inform decision-making

Current meteorological forecasts provide temporal, spatial and intensity information, and sector partners welcome their increasing accuracy and timeliness. Engagement with sector partners through detailed scenario workshops, surveys and interviews highlighted a very strong appetite for additional information beyond meteorological forecasts to support and improve decision making. At the same time, it is important to recognise that during complex, high intensity operations the information needs to be clear and in a form that is accessible and simple to digest. This refers to the ability to access information that is readily interpreted at first sight, i.e. has high usability or user-centred design.

While the focus of this project was on exposure and impact forecasting, sector partners are also keen to have continued, and enhanced, access to meteorological forecasts. Simplistically, this can be considered to be along the lines of the cyclone tracks currently produced by the Bureau, but appropriately adapted to cover other weather events, such as large-scale winds and severe thunderstorm events. Aspects of this baseline concerning uncertainty and interpretation are explored in more detail in **Finding 4**, **Finding 5** and **Finding 6**.

Eight priority information needs relevant to forecasting were identified, with four of these focussed on meteorological and environmental forecasting, one that can be applied to all three information types, two on exposure forecasting and one on impact forecasting (see *Figure 2*, below). We propose that the large proportion of information needs that are meteorologically focussed results, at least in part, may be from the familiarity of agencies with such products and the relatively small leap required to see how their information content can be enhanced to support decision making.

		Priority information needs
Meteorological and environmental	I	**Antecedent conditions** Potential impacts of severe weather events are significantly affected by the antecedent environmental conditions, such as soil moisture content and vegetation.
	II	**Relative intensity for a geographic location** Information about whether the severe weather is atypical for the location, taking into account topography and wind direction.
	III	**Range of meteorological event severity** The range of meteorological conditions that might be experienced within the forecast period, including the best case, most likely case and worst case scenarios.
	IV	**Relevant historical meteorological events** Historical events with similar meteorological forecasts may be useful to support decision making (i.e. historical analogues).
All	V	**Observations versus forecast** Real-time verification of currently valid forecasts against the latest observations.
Exposure	VI	**Location of specific cohorts, including vulnerable cohorts** Information regarding structures supporting vulnerable cohorts such as aged care, health services and schools.
	VII	**Dynamic human considerations** Information regarding people movement arising from seasonal and routine period (e.g. peak tourism for the location, school times).
Impact	VIII	**Disruption to essential services and critical infrastructure** This includes exposure and time to restoration in each location, for energy, water, transport and roads, telecommunications, food and supply chains.

FIGURE 2. PRIORITY INFORMATION NEEDS

Each of these priority information needs are described in more detail below.

Finding 2A: Meteorological and environmental information needs

While focused on meteorological and environmental information, the following four information needs indicate the ability and willingness of decision makers to make use of a range of information types. Used in combination with their training, experience and judgement, the information provides the basis for making qualitative judgements on potential exposure and impact, in the absence of quantitative exposure and impact forecasts.

I. **Antecedent environmental conditions**

Potential impacts of severe weather events are significantly affected by the antecedent environmental conditions and rapid access to relevant condition information is desired. For example:

a. Soil moisture content is considered the most important soil factor for rapid runoff and flash flooding.[15] Saturated soils reduce moisture absorption, resulting in higher runoff regardless of other environmental conditions. Soil moisture content can determine whether a given rainfall event will result in a significant flash flood or not.

   Soil moisture content also impacts the ability of trees to withstand severe winds, as supersaturated soils, in essence, lose strength and this in turn affects the effectiveness of roots to maintain tree stability.

b. Vegetation (live and dead) moisture content, soil moisture, vegetation type and humidity each significantly affect the ability of bushfires to take hold, with wind conditions then contributing to the speed with which fires move. While bushfire is beyond the specific remit of this project, we use it to reinforce the importance of understanding antecedent conditions in emergency response to incidents.

II. **Relative intensity/atypical conditions for a locality**

Sector partners need to know if the intensity of the forecast weather is typical or atypical for the geographic area. For example, trees anchor themselves against prevailing winds by growing roots in a particular pattern. Most of the supporting root structure of large trees grows on the windward side of the trunk. If winds come from an uncommon direction, and with a greater-than-usual speed, trees may be vulnerable to falling.[16] This could lead to increased damage to, for example, housing and above ground electricity and telecommunications infrastructure.

Additionally, depending on local topography, infrastructure and antecedent conditions, atypically large rainfall (intensity or total) could result in flash flooding, resulting in damage to housing, businesses and infrastructure. Flooded roads, in turn, impacts the ability of emergency services to respond to calls for assistance.

III. **Range of meteorological event severity**

Sector partners expressed a strong desire to be informed of the range of meteorological conditions that might be experienced within the forecast period, including 'most likely' as well as the extreme 'worst case' end of the range. Understanding the worst case forecast conditions was driven by the need to be prepared for, and able to respond quickly to, any variation from the expected or mid-range forecasts:

"Being able to see the full range of possibilities is important. [We] accept the fact that this will sometimes result in over preparation, but this is more than compensated for by the appropriateness of response readiness when the extremes are met. [We are] currently operating based on the 10% forecasts. Should the storm not eventuate, it will have been a useful preparedness exercise. It takes hours to put plans in place and severe thunderstorms associated with atmospheric instability evolve rapidly."

QUOTE 1. SECTOR PARTICIPANT ON PREPAREDNESS FOR A RAPID ONSET STORM (WORKSHOP #1)

[15] https://www.sciencedirect.com/science/article/abs/pii/S0022169416301123.
[16] Sector participant, Workshop #3

This indicates sector partners have a level of comfort to manage forecast uncertainty and an appetite to access detailed ensemble meteorological forecasts produced by the Bureau. This information, however, must be tempered with appropriate guidance on the likelihood of the extreme conditions, and specificity regarding the limitations in the modelling that underpins such forecasts.

We note here that there is a wide range of possibilities for describing so called 'worst case' forecasts and it is critical that an agreed, clearly defined and communicated terminology is adopted. Forecasts of 'worst case' should be presented in the context of forecast 'likely' conditions. No specific form of 'worst case' was detailed in the engagement process.

Taken together, the above highlights the important role that embedded meteorologists play in such events in the interpretation of ensemble forecasts.

IV. Relevant historical meteorological events

Sector partners identified that impact information from historical events with similar meteorological forecasts may be useful in identifying the issues that may arise, resourcing required, damage and disruption potential, and emergency relief needs. It was recognised that forecasts will not match precisely with past events, that areas for the forecast impact may have changed (for example, population, building and road infrastructure) and that options available in response may have expanded (for example, better forecasts may lead to better community preparation and warnings). However, the identification of 'similar' events does provide decision makers with a form of baseline from which to operate.

While such information may provide useful guidance to decision makers, some key potential issues were not explored, such as:

- What constitutes a 'similar' meteorological event?
- What is the utility of such information, and does it actually improve decision making?
- Are there sufficient similar historical events (including antecedent conditions) to provide useful information?

Finding 2B: Exposure and Impact Information Needs

The desire for exposure and impact information is underpinned by the need to make decisions to support community safety, and in particular vulnerable cohorts. Through scenario-based exercises with the EM sector, it was found that greater community and human safety considerations were more front of mind than the specific physical impact on residential assets. For example, it may not be possible to protect all physical assets in the path of a fire or flood, and priority is given to actions targeted to community safety.

At the same time, identifying the locations of cohorts that have a greater risk of being impacted, including by loss-of-life and injury, and the risk likelihood and severity, is directly informed by physical exposure and impact forecasting. Exposure and impact forecasts would be valuable in informing key decisions relating to planning evacuations, ensuring the safety of communities, and relocating people to safe zones.

When sector partners turned their minds to impact forecasts, many valued qualitative impact modelling. We note that this is not a statement that qualitative forecasts are necessarily preferable to quantitative forecasts, but rather that there is value in qualitative forecasts, especially in the absence of reliable quantitative forecasts.

Sector partners also expressed interest in the balance between perfect data and rudimentary models for qualitative impact assessments. This balance is, in part, driven by the recognition that 'perfect' data is rarely available on the timescales of decision making during an event, and if models exist that produce insights that are 'good enough' (with an understanding of the limitations of the models), then decision makers have the skills and experience to make appropriate use of such information.

Sector partners noted that information regarding impact (or length of disruption) on infrastructure, transport and critical facilities supporting vulnerable populations would be helpful to support their decision making.

The research, and subsequent operational opportunity, is to make the connection between impacts in the physical world to impacts in the human (and environmental) world. In a sense, it is relatively easy to pose, and in some cases address, the technical question of 'how many physical assets will be affected and how badly?', and this needs to be linked to the questions of 'how many people will be affected, how will be they be affected, and what needs to be done in response?'. In effect, this is akin to building the bridges along a value chain, for example, as discussed by Golding[17] in a slightly different context (see *Figure 3*), linking islands of domain expertise to understand and enable the best possible information to be provided and enable the best possible decisions to be made.

A further research opportunity is to investigate questions around uncertainty in physical impact estimates and the subsequent uncertainty in human impact estimates. It is worth reiterating that EM sector partners that contributed to the scenario analyses made clear that they were comfortable dealing with levels of uncertainty in information and modelling, provided that they were informed of the nature of the uncertainty.

While the following four information needs focus on exposure and impact, it is important to recognise that they require joint capability from the Bureau, GA and/or other providers, such as combinations of predicted hazard tracks overlaid with exposure information for those tracks. To service these needs, adaptations of current Bureau and GA products and services may be required.

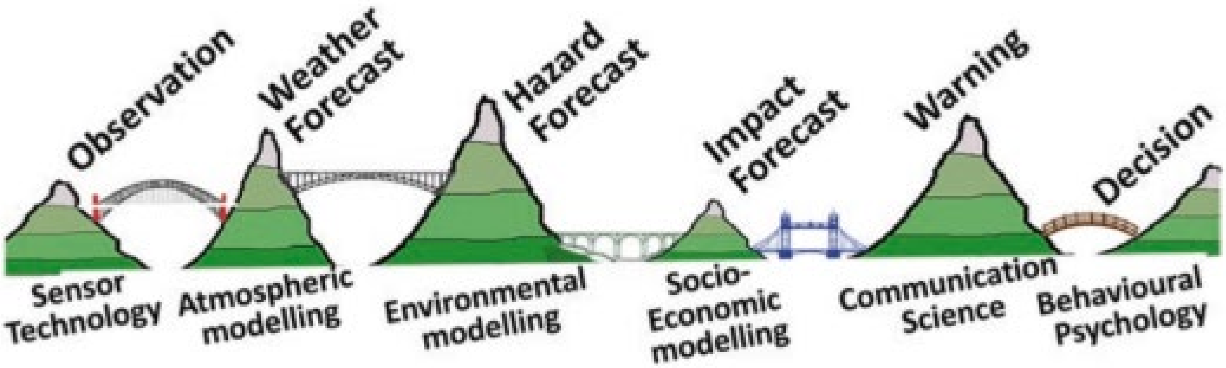

FIGURE 4. THE WARNINGS VALUE CHAIN, TAKING OBSERVATIONS THROUGH TO DECISIONS.

Combined weather, exposure and impact forecasting information need:

V. **Real-time verification of forecasts – monitoring forecast accuracy against the storm track**

In the lead-up to, and during the onset of, a severe weather incident, response agencies are making a wide range of decisions concerning, for example, standing up incident management teams, resource allocation and pre-positioning, coordination with sector partners and providing information to the public. These decisions are being made based, in the main, on weather forecasts at varying lead-times. As the weather system takes hold and begins to impact the community and environment, incident controllers need to be able to identify whether forecasts are being matched by actual observations, and whether there are significant changes to the forecasts. For example, are storm track and intensity forecasts being borne out in reality? If they are not, do previous decisions need to be revisited and if so, how?

Consequently, sector partners expressed a strong desire to receive information updates identifying if observations of weather, exposure and impact are aligning with previous forecasts. Real-time verification is a

[17] Golding, B., 2022: Towards the "Perfect" Weather Warning: Bridging Disciplinary Gaps through Partnership and Communication. Springer Cham, 270 pp.

process of comparison between current observations and currently 'active' forecasts and has the goal of assessing the extent to which forecasts remain 'on track'. Note that this need is somewhat coupled to the desire to understand potential 'worst case' forecasts, as observations differing from forecasts could result, for instance, in transition to a higher state of response than foreshadowed by earlier 'worst case' forecasts.

Exposure information needs:

VI. **Location of specific cohorts, including vulnerable[18] cohorts**, such as aged care, health services, schools

Sector partners indicated a significant need to have exposure forecasting information regarding specific cohorts and facilities that support them, including aged care facilities, hospitals, schools, transient populations (including tourism). Specific cohort information may also extend to geographic areas where multicultural or linguistically diverse communities reside, as there may be cultural reasons for not trusting information provided by authorities, or less experience with similar severe weather conditions.

Sector partner concern extends to the need to identify where transient communities or communities that reside in mobile or non-permanent structures (for example, tents, caravans or remote huts, which are not likely to be identified in a map-based product) and are at greater risk during severe weather events. Information on the potential impact on vulnerable cohorts was identified as a key requirement in both the survey and sector partner workshops.

We heard from sector partners that in many cases, local governments are able to identify community partners who are aware of and/or will identify people with vulnerabilities in each hazard risk location.

Sector partners identified a need for rapid access to information on such cohorts specific to forecast severe weather incidents.

Some of this information is available, for instance, through the GA Australian Exposure Information Platform (AEIP) and more specifically for imminent incidents from the National Hazard Impact and Risk Service (NHIRS) for tropical cyclone track forecasts produced by the Bureau of Meteorology. It is not, however, available as a standard service for all forms of severe weather events.

Sector partners' desire to better understand the impact on vulnerable cohorts is further detailed in **Finding 7**.

VII. **Dynamic human considerations** – people movement arising from seasonal and routine periods

The scale of emergency response actions is influenced by a range of factors, some of which are static on timescales of the order of weeks or months (for example, buildings, infrastructure) and some of which are dynamic on timescales of weeks, days or even hours (for example, movements of school children, workers, tourism generally, large sports and entertainment events).

Understanding the number and nature of people exposed to a developing incident is critical to informing the scale of response required and the potential emergency relief and recovery needs. Moreover, in the case of tourism, holidaymakers may even be considered a vulnerable cohort as they may have a lack of knowledge of their (temporary) local environment, and high numbers of tourists may place a significant stress on local infrastructure and services in the event of an emergency. Just as some people may not understand current forecasts, their decisions may be contradictory to the desired outcome due to their underpinning vulnerability. This has been observed time and time again with people choosing to stay and defend properties from bush fire under forecast catastrophic conditions.

Sector partners expressed a desire to have rapid access to information on such dynamic human considerations.

[18] Individuals who may be regarded as vulnerable may be different in different communities and susceptibility to disaster impact may change over time within communities. The community agencies that support people with vulnerabilities, and business operators that accommodate, employ or provide services to groups that may become highly susceptible in an event, will also vary across communities and change over time. 'People with vulnerabilities in disasters: A framework for an effective local response, Department of Communities, Child Safety and Disabilities', Queensland Government, 2016.

Impact information needs:

VIII. **Disruption to essential services and critical infrastructure** – exposure and time to restoration

Essential services and critical infrastructure can include production, supply and distribution of energy, supply and distribution of water, public transportation of people or freight, roads, telecommunications, sewerage infrastructure, fire-fighting services, hospitals and education. Consequently, it is essential for emergency services response, relief and recovery agencies to understand the likely and potential impact of an event on these services and facilities, while recognising that emergency services will not have direct responsibility, for instance, for ensuring continuity or restoration of these services.

For electricity, this includes not only the potential for power outages and its impacts, but also considering the impact on evacuation if power lines are down across evacuation routes. Food chain suppliers also required information about potential power outages and impact on roads as this would impact decisions about bringing in generators to stores, moving stock, and forecasting potential stock loss.[19]

Exposure and impact forecasting, and in particular, forecasting of restoration times in each locale, will provide valuable information to emergency management decision makers in the (safe) allocation of resources for response, relief and recovery purposes.

We note that forecasting critical infrastructure failure and subsequent restoration times is most likely to fall within the domain of the respective critical infrastructure providers and it may be difficult for, say, Geoscience Australia to gain direct access to such information. On the other hand, this illustrates the need for strong communication between key industry stakeholders and emergency services during the lead up to and onset of a severe weather event.

Implications:

- Identify high-value prospects for implementation from the eight priority information needs identified as possible avenues to strengthen the provision of further decision-making support to EM sector partners. (See **Implication H2.2**)
    - Four priority information needs (**Finding 2a**, **I.-IV.,**) align strongly with Bureau-based capabilities, appreciating some may already be underway, and would be allocated to the appropriate divisions or project teams within the Bureau. Implications to extend scientific and technical capability have been further detailed at **Implication STC1.**
    - Four priority information needs (**Finding 2b, V.-VIII.**) are an extension of Bureau and/or GA-based capabilities and datasets including information types such as the location of vulnerable cohorts, community assets and critical infrastructure. Implications to extend scientific and technical capability have been further detailed at **Implication STC2**.

[19] Sector Partner Workshop #2 (18 August 2023).

Finding 3: Sector partners are currently focused on predicted weather rather than exposure and impact forecasts

Impact prediction is still in its infancy in Australia and internationally. Sector partners are therefore, and understandably, not immediately turning their minds to impact forecasting to support their decision making in preparing for and responding to emergencies.

Rather, sector partners are focused on predicted weather when preparing for and responding to severe thunderstorm and large-scale wind events. We found that sector partners tended to rely on information already familiar to them when making decisions, such as predicted weather, as well as real-time updates on actual impact. This familiarity bias meant sector partners, when asked, tended to prefer information (and formats of information) and processes that are most familiar based on their experience.

In the survey responses, many respondents use current weather forecast information sources as a proxy to understand the potential impact of severe weather. This includes Bureau information, briefings, flood mapping and rainfall data, as well as other platforms such a Windy.com and the Joint Typhoon Warning Centre (JTWC).

Impact information for residential assets

We also note that sector partners did not demonstrate a significant demand for impact information regarding residential assets, despite the obvious influence residential assets damage has on, say, the need for emergency accommodation during response, relief and recovery phases.

In one survey, the majority of the AFAC Flood & Severe Weather Intelligence Services Technical Group (FSWISTG) respondents indicated 'somewhat useful' to the statement, "Impacts to residential properties sit with equal importance as" impacts to other infrastructure and services (transport, energy, healthcare, water, telecommunications, food and grocery)". However, one FSWISTG respondent noted that, "further understanding of residential impacts is a proxy for other impacts that are most valuable for the sector in planning and operations." For example, understanding residential impacts could assist in planning for sufficient resources to respond to SES callouts during a severe weather event.

Proxy indicators

Sector partners noted a desire for forecasts of some other proxy indicators beyond those that can be supported by direct meteorological and impact forecasting, specifically:

- **Number of calls for assistance**, as this determines a significant portion of capacity required during response. Sector partners would further welcome the ability to nuance the type of calls, for example, by those calls for assistance where there may be a health impact rather than a tree down in the yard.
- **Tree fall**, as this in turn influences loss of overhead power transmission and telecommunication facilities, house damage and potential road closures.
- **Flood mapping**, as this in turn influences property damage, road closures, and potential threats to life.

Given that sector partners are currently focused on forecast weather, there is a need to:

- Continue engaging with sector partners to raise awareness of:
    - the relationship between physical exposure / impact forecasts and identifying and quantifying at risk populations (as well as physical assets) during major weather events; and
    - existing exposure and impact forecasting tools and capabilities.
- Consider developing and engaging on exposure forecasting as a step change towards impact forecasting.

Implications:

- Share information with the EM sector including progress and outcomes of impact-based forecasting research activities. See **Implication H1.2**
- Extend scientific and technical capability to include development of proxy indicators for exposure and impact have been further detailed at **Implication STC2**

Finding 4: Sector partners are keen to be provided with information on a range of potential scenarios they may face both before and during an incident

For severe weather events, sector partners want to know and prepare for worst-case scenarios. The need for this information enables responders to identify potential community and asset safety threats and prepare accordingly. That is, the information enables responders to, formally or informally, identify exposed assets and potential physical impacts.

We need to emphasise here that there is not a clear view on a strict technical definition of 'worst-case' that should be applied. For example, given the available meteorological information when the forecast is being made, does worst case scenario mean something akin to 'reasonable worst case' which might happen with, say, 10% probability, or does it mean an 'extreme worst case' which might happen with a 0.5% probability?

It is beyond the scope of this project to resolve this question. We will continue to use the term 'worst case' in a relatively informal sense, and to mean 'a relatively low likelihood event, but within reason for planning and responding purposes. However, it is important, from both technical and practical viewpoints, that the sector develops consistent and well-defined terminology around such concepts.

It is important to recognise that the 'worst case' meteorological event does not necessarily correspond to the worst case exposure or impact event. A simple example would be to consider that the most severe cyclone track from the ensemble might be a Category 5 cyclone making landfall in an unpopulated area, while another cyclone track from the ensemble is a Category 4 cyclone making landfall at a major regional centre resulting in largescale damage to homes and infrastructure. **Consequently, hazard, exposure and impact ensembles will all need to be generated and appropriately presented**. Strong sector partner comprehension of the distinction of meteorological worst case from exposure or impact worst case is critical for initiating the appropriate emergency response. This will require education and continual reinforcement of the distinction with sector partners.

Sector partners value transparency about the limitations of the modelling

Sector partners, especially those decision-makers from the emergency management sector across response, relief, and recovery phases, have the ability to incorporate uncertainty into their decision-making, provided they know the limitations of the models underpinning the forecasts. Given the unpredictability and uncertainty of these severe weather events, sector partners want to know a range of scenarios, including the worst-case scenario, to manage this uncertainty.[20] Sector partners are able to deal with uncertainty in the information provided if the information is in accessible formats, can readily support decision making, and they have a clear idea of the limitations of the data and the range of uncertainty.

Specifically, some sector partners would like to know the likelihood of an extreme worst-case scenario. This information would be even more pertinent for severe thunderstorms, given their unpredictable nature and unstable atmospheric conditions. With rapidly developing storm cells, sector partners noted that it is too late to wait until the storm hits to preposition resources.

Sector partners are also interested in worst-case scenarios as they have eventuated more frequently in recent years. For example, climate change has resulted in heavier rainfall intensity extremes – in effect, what in the past may have been extreme cases have become more commonplace.

[20] Sector Partner Workshop #3 (21 August 2023).

Implication:

- Develop consistent language and terminology for referring to alternative scenarios and associated uncertainty. See **Implication H3.2**
- Consider expansion of the features and functionality contained within NHIRS to include ensemble exposure and impact forecasts. See **Implication STC2**
- Raise user awareness regarding terminology, interpretation of forecast data and understanding potential limitations of data sets and models. See **Implication STC3**

Finding 5: Decision making support should recognise high cognitive load

Impact forecast information should be provided to support decision making and empower decision makers, rather than making the decisions for them. This decision-making support should be provided in ways that recognises the high cognitive load on response agency personnel during an event.

Managing a high cognitive load

Many sector partners are concerned about information overload and the risk of decision paralysis due to being provided with excessive data. When responding to severe weather events, response agencies collate vast amounts of incident information to better understand the full impact of the event and receive a range of information from various sources and in different formats. Response agencies are also continuously re-evaluating decisions, based on updated or new information.

Impact forecast information should be in a format that is highly accessible. Currently, sector partners are using a range of tools, and will use the tools available that best meet their needs, regardless of the source (e.g., streamlined and aesthetic graphical presentation).

Some sector partner suggested this could be a dataset that could feed into the backend of their existing platforms or portals, rather than a new portal. Others prefer a visual depiction of temporal, spatial and severity forecasts. For example, during the scenario testing workshops, sector partners described wanting to see the path of the storm on a map.

Further work is required to better understand how best to resolve the varying needs of the sector partners and other stakeholders and develop solutions that can readily support sector partners during times of high cognitive load.

Embedded impact experts

Best practice and learnings in translating meteorological forecasts to support decision making could be used to inform the future of exposure and impact forecasting in Australia.

Embedded meteorologists have played a critical role in managing uncertainty of meteorological forecasts. Embedded meteorologists communicate with response agencies and interpret meteorological data. We heard from sector partners that having a subject-matter expert available to translate complicated information into something usable for decision makers is highly valued.

For example, embedded meteorologists provide nuanced and technical information when decision makers require more specific detail about the severity and range of possibilities of a weather event, often in the context of bushfires and cyclones. Embedded meteorologists are able to provide further information, in real time, about the likelihood of winds being 100km/h versus 110km/h but are not in a position to provide a refined analysis of damage that results from different windspeeds.[21] In a similar way to embedded meteorologists providing subject-matter expertise (SME) on meteorological forecasts, equivalent impact SMEs could play a role in interpreting ensemble exposure and impact forecast data to support decision makers within the IMT.

Implications:

- Continue collaborating with the emergency management sector to build awareness of exposure and impact forecasting, and better understand the sector's operational needs. See Implication H1.1-1.3

[21] Sector Partner Workshop #1 (17 August 2023).

- Develop and implement techniques and methods for readily communicating and interpreting detailed technical information in an accessible form. See **Implication STC3**
- Develop appropriate educative materials to raise user awareness and support the understanding of terminology, interpretation of forecast data, and understanding of potential limitations of data sets and models. See **Implication STC3**

Finding 6: Sector partners are seeking exposure and impact information from a variety of sources

Sector partners valued the capability and datasets provided by NHIRS. However, in better incorporating impact forecast information in their decision making, sector partners sought a richer dataset, to include not just residential buildings but also other structures to support response activities. The information sought by sector partners goes beyond that which is currently supported by GA platforms such as AEIP and NHIRS. AEIP has information on most built assets, however it is an aggregate format which may not be useful for sector partners. Further, neither AEIP nor NHIRS currently have the ability to support dynamic exposure information, such as time of day or seasonal estimates of populations (e.g. special event and tourism numbers).

Specific information sought by sector partners include:

- Structures that support vulnerable cohorts (e.g. schools, hospitals, aged care)
- Structures to support response and relief activities (e.g. buildings to shelter people).
- Critical infrastructure exposure and impact (e.g. power lines).
- Temporal human aspects (e.g. school hours, holidays, special events).

One sector partner noted that the large-scale wind element of NHIRS has been a "game changer" for those areas not in the tropical cyclone regions and would see much value in expanding NHIRS to be a portal to also encompass other hazards such as tsunami and flood.[22]

However, it has been recognised that there are challenges in developing a national dataset to support all the above. Sector partners expressed appetite for a nationally consistent dashboard or dataset that could provide impact forecasting information. This would be particularly useful information when sector partners are dealing with cross-border emergency events. While GA is aiming for nationally consistent information across NHIRS, ensuring data is nationally consistent may result in data degradation if a 'lowest common denominator' approach is adopted. There is opportunity to improve the consistency of data through uplift from jurisdictions and advocacy by sector partners.

There is also inconsistency in the terms and language used to describe aspects of hazard, exposure and impact between jurisdictions and between hazards. In developing future products, datasets and impact forecasting information, sector partners also want consistency (and clarity) on terminology. Specifically, for predicting the impact of severe thunderstorms and large-scale wind, there is value in better defining or quantifying terms such as 'possibility' or 'likely'. There is a need for a consistency in language across the impact forecasting landscape.

Implications:

- Timely access to a range of appropriately presented information, spanning meteorological, exposure and impact forecasts, would support real-time decision making for EM sector partners. To achieve this goal, continue collaborating and building awareness of exposure and impact forecasting with the emergency management sector. See **Implication H3.1**
- In partnership with sector partners, develop an agreed vocabulary and terminology with respect to meteorological, exposure and impact forecasting, consistent where possible, across hazards and across community and physical assets. See **Implication H3.2**

[22] Respondent #3, Sector Partner Survey.

- A future exposure and impact forecasting research project should investigate the feasibility of, and techniques for, undertaking real-time verification of forecasts against observed exposure and impact. See **Implication STC1**
- Expand the features and functionality, for example, similar to that contained within NHIRS, to include identification and location of vulnerable cohorts, community buildings and critical infrastructure, amongst other things. See **Implication STC2**
- Develop appropriate educative materials to raise user awareness and support the understanding of terminology, interpretation of forecast data, and understanding of potential limitations of data sets and models. See **Implication STC3**

Finding 7: Sector partners seek to understand the impact on vulnerable cohorts

Sector partners want to understand the potential impact on vulnerable cohorts and the structures that support these cohorts, such as schools and aged care facilities. Other at-risk cohorts during a disaster event, include tourists, campers and communities who do not reside in residential structures (e.g. caravans).

This sentiment was reflected in both responses to the survey as well as in the end-user workshops. In the survey, when asked to describe the impact information respondents would like to have to support their decision making, many stated a desire for information about the severe weather event impact on facilities to support vulnerable populations such as health facilities, aged care, and schools. Survey respondents in particular, sought this information in the response planning phase (3-7 days out from an event).

In the end-user workshops, sector partners wanted to know both the potential and actual impact on community assets such as aged care facilities. We heard from sector partners that this impact information would support how they prioritise response activities, resourcing, and communications.

Impact information about vulnerable cohorts would allow them to check on facilities such as aged care homes, hospitals and places supporting vulnerable populations impacted and direct them to activate their emergency plans.[23] This impact information also would allow sector partners to focus resources on higher risk members of the community—those most vulnerable and showing the greatest residual impact.[24] Some sector partners also considered how the impact information would inform their communications activities. For example, for school communities potentially impacted, sector partners would need to consider developing communications to parents, schools and other providers in the impacted area.[25]

Implications:

- Continue developing and engaging on exposure forecasting as a step change that progresses sector partners to using impact-based forecasts. See **Implication H3.1**
- Explore benefits and appetite for operationalising existing decision-making support systems. See **Implication H3.3**
- Develop the business case for the development of an enhanced exposure and impact forecasting system. See **Implication H3.4**
- Expand the features and functionality, for example, similar to that contained within NHIRS, to include identification and location of vulnerable cohorts, community buildings and critical infrastructure, amongst other things. See **Implication STC2**
- Develop appropriate educative materials to raise user awareness and support the understanding of terminology, interpretation of forecast data, and understanding of potential limitations of data sets and models. See **Implication TC3**

[23] Sector Partner Workshop #2 (18 August 2023).
[24] Sector Partner Workshop #1 (17 August 2023).
[25] Sector Partner Workshop #1 (17 August 2023).

Finding 8: Existing capability within GA and the Bureau and/or other information providers is a strong fit to supporting the needs identified by the sector partners

The emphasis on more sophisticated information on meteorological forecasts and the potential value identified in exposure and impact forecasts voiced by the sector partners is extremely well aligned with the capabilities of the project partners generally, and more particularly with the detailed technical skills within the Forecast Innovation Team, Radar Science Team and High Impact Weather Team of the Bureau and the Atmospheric Hazards Team of Geoscience Australia.

To address the full range of measures of interest expressed by the sector partners, it would be necessary to initiate a number of research and smaller prototyping efforts that potentially go beyond the existing capabilities of the partners. Such projects range from, for instance, forecasting tree fall during significant weather events through to the modelling of seasonal and daily human movements through the year.

The National Hazard Impact and Risk System (NHIRS) already provides a demonstration that technical information on meteorological forecasts (specifically cyclones) can be combined with asset-based information to provide exposure and impact forecasts in a timely and useful manner to sector partners.

The opportunities are to:

- refine the manner in which the information is provided, based on user needs,
- to provide exposure and impact-based information across the various hazards in a consistent manner, where possible,
- communicate the value and limitations of impact-based forecasts,
- operationalise the system providing this information, recognising that operationalisation typically requires 24/7 support backed up service agreements.

Implications:

- Continue collaborating and building awareness with the EM sector. See **Implication H1.1-1.3**
- Extend scientific and technical capability in line with sector partner information needs. See **Implication H2.-2.2**
- Consider a phased approach to providing enhanced information for decision-making, focusing initially on exposure forecasting, followed by impact forecasting. See **Implication H3.1-3.4**

Implications

While the Bureau and Geoscience Australia are national bodies with statutory obligations, responsibility for managing and mitigating the impact of severe weather is a jurisdictional responsibility. And recently, perhaps as a consequence of complex and compounding severe weather events of the last few years, strong inter-jurisdictional and national forums for addressing how to better predict the impacts of severe weather have emerged in the emergency management sector. As maturity grows across the EM sector, the language and capability around severe weather forecasting (or hazard forecasting) will develop into exposure forecasting and impact forecasting.

It is in this context that high level and scientific and technical capability Implications have been identified from the research findings and outlined below. Only those Implications considered to have high impact for sector partners have been provided in this report.

High level implications

Implication		Relevant finding(s)	Estimated work effort[26]
Implication H1 Timely access to a range of appropriately presented information, spanning meteorological, exposure and impact forecasts, would support real-time decision making for EM sector partners. To achieve this goal, continue collaborating with the emergency management sector to build awareness of exposure and impact forecasting, and better understand the sector's operational needs.	H1.1 **Build EM sector awareness** of existing tools and capability, and the potential benefit of applying exposure and impact forecasting in their decision making.	Finding 1 Finding 5 Finding 8	High
	H1.2 **Share information with the EM sector.** This includes progress and outcomes of impact-based forecasting research activities.	Finding 3 Finding 5 Finding 8	Low
	H1.3 **Engage with other industry stakeholders**. This includes energy, water, food supply chain and insurance stakeholders.	Finding 5 Finding 8	Medium
Implication H2 Extend scientific and technical capability in line with sector partner information needs.	H2.1 **Engage with the cross-section of sector partners and industry stakeholders** who have registered interest to contribute to the development roadmaps of the Bureau, GA and other providers. This may include developing detailed and agreed business requirements for the eight information gaps identified, user testing of tools or development of other functionality.	Finding 1 Finding 8 Finding 1	High
	H2.2 **Identify high-value prospects** for implementation, based on outcomes of H2.1, noting that a number of high-value prospects have been identified and are detailed in *Table 3. Scientific and technical capability implications* below.	Finding 2 Finding 8	High

[26] Estimated work effort has been provided by the research team based on existing capability and experience regarding the nature of work involved. This has been provided for guidance based on complexity of the work required and will need to be verified.

Implication H3 Consider a phased approach to providing enhanced information for decision-making, focusing initially on exposure forecasting, then followed by impact forecasting.	H3.1 **Continue developing and engaging on exposure forecasting** as a step change that progresses sector partners to using impact-based forecasts.	Finding 6 Finding 7 Finding 8	High
	H3.2 **In partnership with sector partners, develop an agreed vocabulary and terminology with respect to meteorological, exposure and impact forecasting**, consistent where possible, across hazards and across community and physical assets. Embed this terminology within existing training and information resources, such as the Australian Disaster Resilience Glossary[27].	Finding 4 Finding 6 Finding 8	Medium
	H3.3 **Explore benefits and appetite for operationalising existing decision-making support systems** such as NHIRS impact reports, including identifying any information access and security issues that may arise, for example, with the sharing of information concerning critical infrastructure.	Finding 7 Finding 8	Medium
	H3.4 **Develop the business case for the development of an enhanced exposure and impact forecasting system**, including what would be required to reach the threshold for initiating development of the system.	Finding 7 Finding 8	Medium

TABLE 2. HIGH LEVEL IMPLICATIONS

[27] https://knowledge.aidr.org.au/glossary/?wordOfTheDayId=&keywords=&alpha=&page=1&results=50&order=AZ

Scientific and technical capability implications

The following implications focus on extending the scientific and technical capabilities held by the project sponsors, the Bureau and GA. This includes building on the functionality of the existing National Hazard Impact and Risk Service (NHIRS) platform. The implications consider existing Bureau and GA capability that may be readily adapted or propose the development of new exposure and impact services by the Bureau, GA and/or other industry providers, as appropriate. The implications in *Table 3. Scientific and technical capability Implications* are intended to apply on a multi-hazard basis (that is, for large scale winds, severe thunderstorms, flood, cyclone and/or bushfire) as funding and resourcing allows.

Scientific and technical capability implications (STC)	Relevant finding(s)
Implication STC1: Consider expanding on the meteorological features and functionality supported by the Bureau to include: i. **Antecedent environmental conditions** relevant to EM sector partners. ii. Information on the **relative intensity and atypicality** of forecast conditions for affected localities. iii. Information on the **range of conditions** (from most likely to reasonable worst case) that may be expected during an event, for example, detailed information from ensemble forecasts. iv. Information on **relevant historical meteorological events** that might assist EM sector partners in planning response activities.	Finding 2A Finding 2B Finding 6
Implication STC2: Consider expanding on the features and functionality contained within Bureau and GA's information products to include: i. **Real-time verification** indicating accuracy of most current forecasts against observations. ii. Ensemble exposure and impact forecasting capability. iii. Identification, quantification and location of vulnerable cohorts, including but not limited to aged care centres, schools, mass gatherings and transient communities. iv. Identification and location of community buildings and critical infrastructure, and where possible, the development of applicable vulnerability models for those assets. v. Development of proxy indicators for exposure and impact, methodology to be further validated with sector partners, for example, ○ Number of calls for assistance ○ Tree fall forecasts (number, location) ○ Flood mapping (noting that this information may be already available to some segments of the EM community through locally available products and services) ○ Seasonal booking numbers for national parks (e.g., campsites, park passes). vi. A longer-term research question should explore the link between forecasts of physical impact and subsequent social impacts, with a view to rapid estimation of impacts informing response, early relief and recovery decision-making.	Finding 1 Finding 2B Finding 4 Finding 6 Finding 7 Finding 3 Finding 8
Implication STC3: Develop and implement a communication and engagement approach with sector partners to support the communication and interpretation of detailed technical information in accessible formats during an incident, including: i. Data provided by the Bureau and Geoscience Australia, and the limitations of the models underpinning the outputs.	Finding 4 Finding 5

ii.	Methods for communicating uncertainty and/or the limitations of meteorological, exposure and impact forecast information products.	Finding 6
iii.	Methods for consolidating, synthesising and simplifying the presentation of information from a range of sources, including, for example, connection of services in ArcGIS Online (AGOL) or similar platforms.	Finding 7 Finding 8
iv.	Appropriate materials to raise user awareness and support the understanding of terminology, interpretation of forecast data, and understanding of potential limitations of data sets and models.	

Table 3. Scientific and technical capability Implications

Appendix 1: Sector engagement

The following engagements were conducted between April 2023 and November 2023. They included an online survey, interviews, sessions with key expert groups and scenario-testing workshops with sector partners.

Engagement	Purpose	Participants
Sector Partner Survey	To understand the sector's information needs about the impact of severe weather events and inform workshops with sector partners.	166
Targeted interviews (x3)	Multiple engagements with subject matter experts to: • Understand the sector's information needs about the impact of severe weather events • Understand existing projects and capability in Australia and internationally	4
Sessions with FSWISTG (x2)	Two engagements with AFAC Flood & Severe Weather Intelligence Services Technical Group (FSWISTG) to: • Provide an overview and receive feedback on project design, including key objectives, engagements and deliverables • Understand state and national priorities for predictive services capability • Test and validate key themes and findings from sector partner engagement	19
Sector Partner Workshops (x3)	To facilitate an in-depth analysis of two complex scenarios involving large scale winds and severe thunderstorms with sector partners and industry stakeholders. Participants included representatives from state and local government, power and water utilities, telecommunications carriers, national supermarket chains and outdoor education providers. The third workshop was an in-person exploration and validation session with experienced sector partners from AFAC.	26 (Workshop 1) 22 (Workshop 2) 2 (Workshop 3)
Targeted consultations with Sector Partner Collaboration Groups	• AFAC Community Engagement Technical Group • AFAC State Emergency Service (SES) Community Safety Group	31
Knowledge Sharing Forums	NHRA Research Forum, May 2023, Melbourne	
Conferences	Innovation Day at the AFAC Conference, August 2023, Brisbane	

Appendix 2. Summary of online survey highlights

Access the summary of online survey highlights here.

Appendix 3. Scenario workshop outputs

Access the scenario workshop outputs here.