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Putting predictions in public: professional perspectives on the risks and benefits of changing wildfire warning systems

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ABSTRACT

Recent experiences of intense wildfire events in fire-prone landscapes have sparked interest and investment in the use of wildfire simulation models and other predictive tools to inform the development of effective warning systems. As projections of increasingly intense and frequent wildfires eventuate, there is growing interest in the inclusion of more predictive intelligence in public warnings to mitigate disastrous losses during and prior to fire events. Predictive fire spread maps (FSMs) show the predicted extent of a given wildfire and have occasionally been shown to the public as a form of hazard information in Australia. Existing literature and inquiry recommendations have highlighted a need for evidence-based research to support the translation of such novel technologies into practice. Our research, which involved interviews with 44 sector experts, explores emergency management professionals' current uses of predictive FSMs, and their views on the potential release of such maps to the public in the future. This article investigates the cultural and institutional constraints underlying the implementation and uptake of predictive technologies and intelligence by its users. Although specific to the Australian context, the findings of this case study offer valuable insights for others considering the integration of novel predictive tools into public warning systems.

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Warnings; wildfire; predictions; professionals; Australia

Key policy highlights

- Policymakers should consider the potential benefits and risks of releasing more predictive intelligence such as predictive fire spread maps (FSMs) to the public. Such warning

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products can provide valuable information to help people make informed decisions about their safety during a wildfire.
- Policymakers should invest in research to better understand the social and institutional factors that influence the use of warnings products based on predictive intelligence. This research can help to identify the best ways to design and implement such products to ensure that they are used effectively by both professionals and the public.
- Policymakers should engage with emergency management professionals to develop guidelines for the release of such warning products. These guidelines should include criteria for producing, communicating, and disseminating these products.

1. Introduction

In the context of intensifying natural hazards, the delivery of timely and accurate warnings about hazard risks and events has become increasingly important (Bean et al., 2015). Alongside evidence of the growing frequency and intensification of wildfires, for example, recent experiences of intense wildfire events in Australia, Greece, Canada, California, and elsewhere have sparked interest and investment in established or new public-facing warning systems and products (e.g. RCNNDA, 2020; Whittaker et al., 2013). Such systems and products are designed to reduce the impacts of hazards events by warning publics about potential risks and impacts in advance of and during an event. In parallel, researchers, practitioners, and policymakers have variously endeavoured to ensure these systems are not only relaying credible information but also that their design and implementation is based on evidence regarding what information at-risk publics want and need at a specific point in time (e.g. Cao et al., 2016; Padilla et al., 2017; Ruginski et al., 2016).

In Australia, as internationally, these warning systems have changed rapidly with the development of mobile networks and technologies. Text-based warnings first utilised in the 2000s were complemented by official apps in the 2010s, often delivering a mix of textual and visual information to individuals' phones and on social media platforms. Warnings relating to wildfires and floods, for example, now typically include maps showing the extent and location of the area likely to be affected within the short-term. Parallel to these technological developments in communication, emergency management agencies have also entered a 'transitional moment' due to their increased technical capacity to predict hazard behaviours and impacts (Neale & May, 2018). Simulation models are now used routinely to inform agencies' operational and planning decisions, including when and how to warn publics about fire events; however, to date these models' predictive fire spread map (FSM) outputs are rarely shared with the public.

An exception to this separation between warnings and predictions occurred in the 2019–2020 Black Summer wildfire season, when several emergency management agencies in southeast Australia released predictive FSMs publicly (see Figure 1). Subsequent research suggested these maps were highly valuable to the public (Whittaker et al., 2021), aligning with both the long-term trend of official inquiries supporting greater use of predictive intelligence (Neale & May, 2018) and providing publics with more information and intelligence within warning products (e.g. RCNNDA, 2020). However, several years after Black Summer, both research and policy lag behind sector

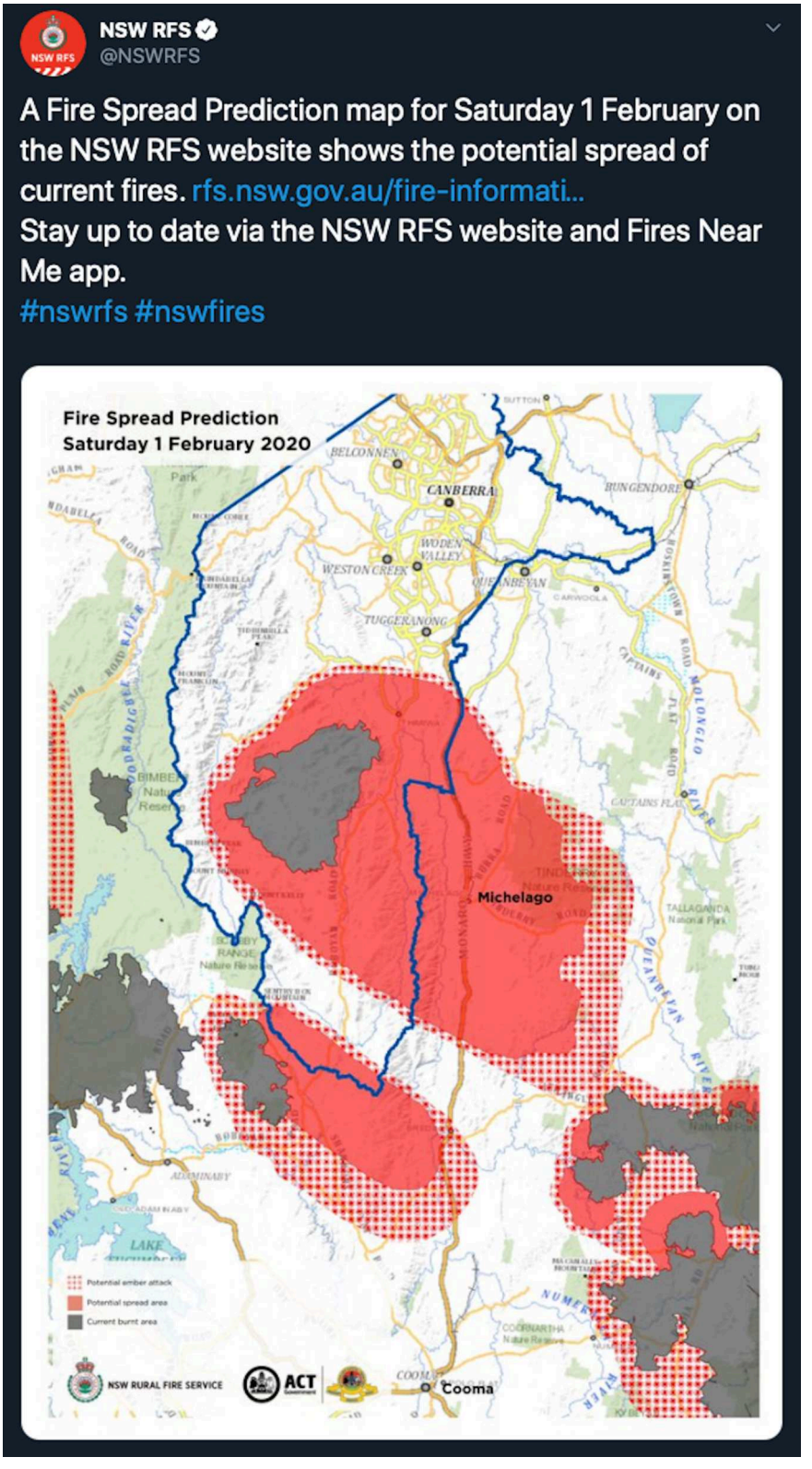

Figure 1. Predictive fire spread map released publicly in February 2020.
Source: X/Twitter.

practice. Australian agencies have yet to develop policies regarding when predictive FSMs can or should be released publicly, and relatively little is known about their optimal design, practical use, or the potential impacts. Informed by studies highlighting the influence of social and institutional factors on technology use, our research responds to this context by seeking to understand the issue as one of cultural change within emergency management.

This article reports on a study conducted as part of a larger project aiming to understand the current and future uses of predictive intelligence within Australia's emergency management sector through a case study of predictive FSMs. This study centred on interviewing sector professionals about the potential future release of predictive FSMs to the public. Participants generally supported such releases while also identifying a range of benefits, risks, and barriers to achieving this end. Alongside technical factors (Neale et al., 2023), all participants drew attention to the sector's cultural and institutional context as decisive to the future of this novel warning product. Even amidst public enthusiasm for more detailed and timely warnings, and alignment with official recommendations, practitioners did not think the predictive intelligence they regularly use would inevitably become publicly available. On the basis of our study, social and institutional factors more than technical feasibility ultimately determine the uptake of new warning products and technologies.

In the following sections, we first review existing literature relating to the design, implementation, and use of warning and predictive intelligence systems, focusing on those relating to wildfires. Second, we describe the design and methods of our study. Third, we present the results of our analysis, concentrating on the risks and barriers that participants felt the public release of predictive FSMs would have to negotiate. These include not only risks to the public, but also risks to practitioners, agencies, and governments, as well as the institutional barriers of conservatism. As we discuss in the final section, these findings support existing analyses of the factors that shape the use of technical systems in natural hazards management generally and have implications for future research on hazard warning products and platforms internationally.

2. Literature review

An established literature on natural hazard warning systems underscore the critical role of timely, consistent, accessible and actionable warnings in mitigating the impacts of hazard events (e.g. Sadiq et al., 2023; Šakić Trogrlić et al., 2022; Tupper & Fearnley, 2023). Recent severe wildfires in British Columbia, southeast Australia, Greece, Hawaii, and elsewhere have revealed enduring gaps in such systems and subsequent inquiries and reviews have synthesised practical and policy lessons useful to improving their effectiveness (Neußner, 2021; RCNNDA, 2020; Sadiq et al., 2023; Tupper & Fearnley, 2023). Overall, we highlight two key trends across the international literature on warning systems. First, many jurisdictions are moving towards greater standardisation in warning messages and visualisations across hazards, in large part to improve their effectiveness and accessibility (e.g. Fearnley et al., 2012; Neußner, 2021). Second, warning systems' persistent gaps relate more to stakeholder engagement than technical capability (e.g. Fakhruddin et al., 2020; Sadiq et al., 2023; Scolobig et al., 2022; Stewart, 2024), underscoring the importance of building public trust and literacy in relation to warnings

(Garcia & Fearnley, 2012; Kelman et al., 2018). While such studies have emphasised the need for co-design with publics (Scolobig et al., 2022) and research regarding what public needs (Mowbray et al., 2024; Sadiq et al., 2023), less attention has been paid to how warnings are developed and utilised by professionals (Reddy, 2023); the experiences and preferences of those who build and operate warning systems remain understudied.

Alongside these developments, many emergency management agencies are integrating a greater number of predictive technologies to support operational and planning decision-making. This has been enabled by many factors including faster hazard behaviour simulators, capable of producing stochastic or probabilistic predictions of a given real or potential hazard event (e.g. Chen et al., 2019; Lourenço et al., 2021). Well-known examples include the European Flood Awareness System (EFAS) (Demeritt et al., 2013), and U.S. Wildland Fire Decision Support System (WFDSS) (Noonan-Wright et al., 2011), as well as forecasting systems used for other hazards (e.g. Fearnley, 2013). In Australia and elsewhere (Kennedy, 2020), predictive analysis of wildfires using simulators have risen prominence in the last 15 years for a range of purposes, including providing 1–7 d predictions of wildfires to support operational decision-making (see Neale et al., 2021; Neale & May, 2018). While such Decision Support Systems (DSSs) are often justified as offering more scientifically-based evidence for emergency managers, research on their implementation highlights the significant influence of social and institutional factors (e.g. Fillmore & Paveglio, 2023; Neale & May, 2018; Rapp et al., 2020). These factors include the preferences and values of DSS users and their audiences, suggesting that intersubjective trust and personal and institutional risk tolerance are more important factors in the use of predictive analyses than their scientific rigour or accuracy (e.g. Calkin et al., 2013; Rayner et al., 2005; Roncoli et al., 2012; Wibbenmeyer et al., 2013).

Implementing new DSSs or warnings systems, or newly integrating intelligence from DSSs into warning systems, therefore requires greater attention to the social and institutional context of implementation. In their international review of wildfire DSSs, Pacheco et al. (2015, 10-14) note that the path to implementation involves multiple stakeholders and is often 'not clear' and non-linear, with positive evaluation of a DSS often relating more to social factors (e.g. peer esteem) and institutional factors (e.g. resourcing) than technical factors (e.g. resolution of intelligence) (see also Cowan & Kennedy, 2023; McFayden et al., 2024; Morss et al., 2005; Rayner et al., 2005). This aligns with literature in the wider field of environmental DSSs underscoring the non-linearity of technology adoption, with multiple possible reasons that a new technology is evaluated as 'accessible, credible, and salient in the eyes of its users and audiences' (Hamilton et al., 2019; Walling & Vaneeckhaute, 2020). Nonetheless, one common factor supporting DSS implementation identified across studies is the integration of stakeholder groups into development and governance, building personal and institutional investment in its adoption (Garcia & Fearnley, 2012; Golding, 2022). Despite this broad consensus, there has been relatively little empirical research into the implementation of either warning systems, DSSs, or the integration of predictive intelligence from DSSs into warnings, amongst the natural hazard management professionals determining these technologies implementation.

As we have highlighted, the simultaneous growth of both emergency management agencies' warning systems and predictive capacity has correlated with an increasing

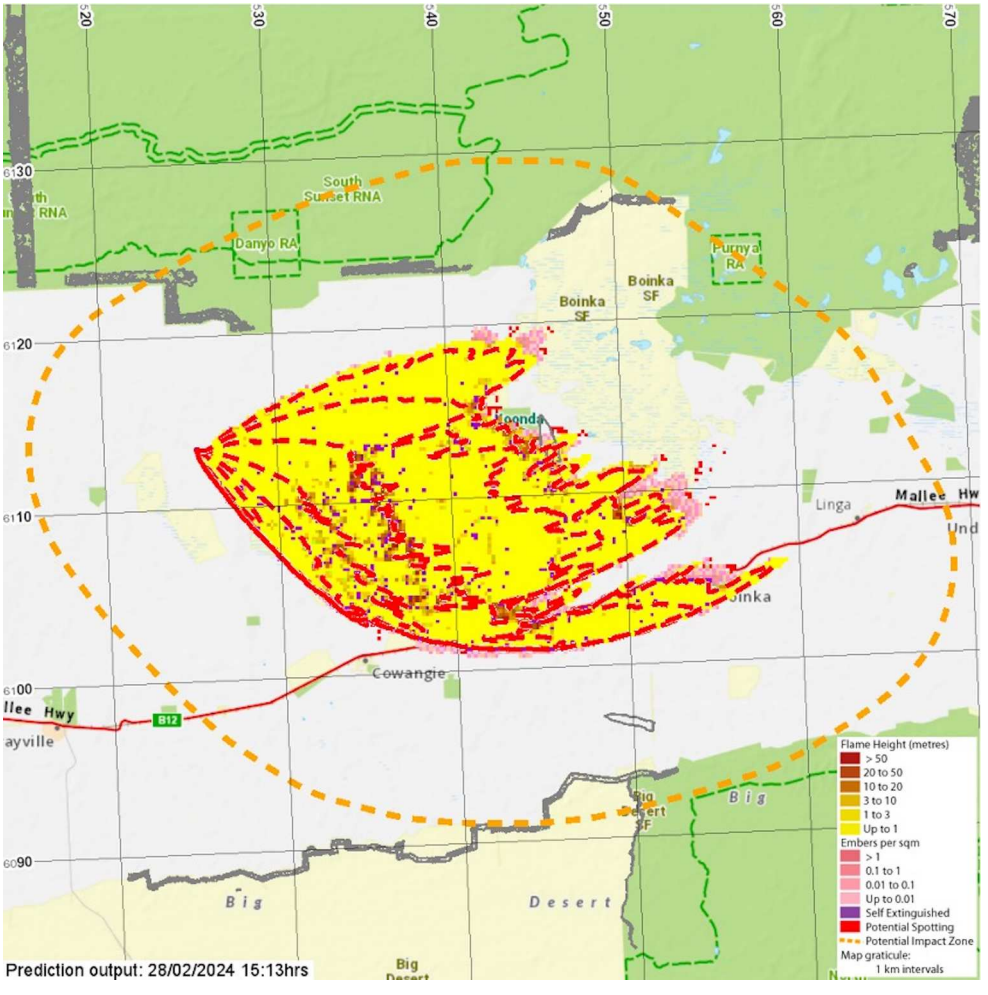

Figure 2. Predictive fire spread map of the type commonly released within emergency management agencies.

Source: [Author 2].

integration of the latter into the former. This was demonstrated in Australia during the 2019–2020 wildfires, as agencies for the first time publicly released predictive FSMs usually only developed for agency decision-makers (Whittaker et al., 2021) (see Figure 2). Existing studies, reviewed above, suggest that there is an urgent need to understand the potential social and institutional factors influencing such technological innovations. Our research responds to this gap, alert to the public interest in integrating predictive intelligence into warning systems and also to international and domestic support for greater standardisation of natural hazards warning systems (e.g. Clark, 2021). We reiterate the need for research that empirically examines the factors influencing the use of predictive intelligence in public warnings. This is why we sought to understand the views of wildfire management professionals who may determine the success of such tools' implementation.

3. Data and methods

This study adopted a case study design to investigate the knowledge gap regarding the benefits, risks, and barriers to the adoption of predictive FSMs specifically and new warning systems more generally. While this case study is focused on Australian states and territories, its findings have implications for researchers, practitioners, and policy-makers in other wildfire-prone jurisdictions with similar emergency management arrangements such as in North America, New Zealand and Western Europe.

The sampling approach of this study was non-random, working in collaboration with the National Council for Fire and Emergency Services' Predictive Services Group and Warnings Group to generate a pool of over 100 possible participants with suitable experience and expertise. The research team refined this list for representativeness, seeking to recruit participants from all Australian federal, state, and territory jurisdictions and across the relevant role domains (public information and engagement, predictive services, incident control). Ultimately, we recruited 44 participants (see Table 1), a significant sample considering the sampling framework and overall potential pool.

Participants' individual interviews lasted 60–90 minutes and occurred over video-conferencing and in person between 25 July 2022 and 3 October 2022.[1] Using video-conferencing made it feasible to interview participants across Australia within a short timeframe, creating consistency across participants regarding relevant policy and technological developments. Interviews were audio recorded, transcribed, and then coded using the qualitative analysis software NVivo 10 according to common themes, structured by the questions (descriptive codes), and emergent themes (thematic codes) to identify points of consensus and disagreement (Cope, 2005). An initial selection of four transcripts was coded separately by [Authors 1 and 2] and then compared, to ensure coding integrity and consistency, and the remainder were then coded by [Author 1].

Below we present the results of our data analysis, organised according to key emergent themes (thematic codes) relating to the project's aim of understanding how emergency services professionals would prefer predictive FSMs to be distributed and used by the public. Interviews were semi-structured, providing room for participants to guide the conversation, however core issues raised in the interviews included: what information predictive FSMs should contain to be effective; how they hoped predictive FSMs would be used; and the primary potential obstacles to releasing predictive FSMs. Quotes from interviews are presented below to give voice to the participants and have been attributed using a

Table 1. Study participants, including jurisdictions and domains of responsibility and expertise.

Jurisdiction	Total	Public information	Predictive services	Incident control
Australian Capital Territory (ACT)	3	1	1	1
New South Wales (NSW)	7	4	2	1
Northern Territory (NT)	3	2	N/A	1
Queensland (Qld)	4	1	2	1
South Australia (SA)	7	3	2	2
Tasmania (Tas)	4	1	1	2
Victoria (Vic)	6	4	1	1
Western Australia (WA)	6	3	1	2
Commonwealth (Federal)	4	3	1	N/A
Total	**44**	**22**	**11**	**11**

code to protect their anonymity, revealing the jurisdiction and specialisation of each participant only (e.g. 'Fed PI1' for Federal public information expert #1; 'Vic PS1' for Victorian predictive services expert #1; and, 'WA IC1' for Western Australian incident control expert #1, etc.).

4. Findings

Our presentation of findings is structured according to the themes of analysis, focusing on practitioners' perceptions of the benefits and risks of releasing predictive FSMs to the public, and the obstacles to doing so. We also highlight practitioners' own ideas for producing, communicating, and disseminating predictive FSMs in the future.

4.1. Benefits of releasing predictive FSMs as a new public information product

Those we interviewed were generally positive about the potential release of predictive FSMs to the public during wildfires and none were explicitly opposed. Key to this overall position were the benefits that participants felt would result from providing this new intelligence, leading to improvements in public risk awareness and safety and enhancements in the credibility and reputation of agencies. Notably, a few participants expressed a sense that widespread use of predictive FSMs was 'inevitable.' To quote one participant, official inquiries after the 2019–2020 disaster 'had plenty to say about that when people were asking, you know, 'What did you want?' 'We wanted more maps'' (Qld IC1).

Virtually all participants identified increased public risk awareness as the most important potential benefit, with many stating that sharing predictive intelligence would enable the public to make more informed and timely decisions during emergencies (cf. Lindell & Perry, 2012; Scolobig et al., 2015).

[2] For example, some drew a linear connection between information provision, awareness, and decision-making, such that 'the more information that we're giving them, probably the more educated they become and then the better decisions they make become as well' (NSW PI2). This benefit was described by others as closely linked to ideas of individualised responsibility 'so if you're responsible for your safety, then I have to give you as much information as I can to allow you to be responsible for your safety' (SA-IC1). Agencies producing and publishing internal predictive intelligence 'arms [the public] with knowledge and equips them with better knowledge around making an effective decision and a conscious decision' (Tas IC1). 'Any information that can help people to make decisions to keep themselves safe,' one practitioner avowed, 'I think is worth sharing' (WA PI1).

Alternately, discussion of appropriate pathways for the release of predictive FSMs suggested that participants shared common caveats about maximising any benefits to public safety. The most widespread caveat was that predictive FSMs should not be released by default for the vast majority of wildfires, but rather reserved for only the most impactful fires during extreme or catastrophic fire weather conditions. 'I see the benefit as we release it on days that are really bad,' as one participant stated, 'we release it on the equivalent of [the 2015] Pinery fire and the message from my perspective

is 'we're not mucking around'' (SA IC1). One participant recalled their experience sharing a predictive FSM at a community meeting, reflecting on how 'they can visually see 'oh my God, this is going to happen' … There's no doubt about that, that changed people's minds who would not have left [without it]' (Vic PI2). Rarely using predictive FSMs would, several suggested, help mitigate 'warning fatigue' (Anderson-Berry et al., 2018) and prompt publics to pay attention and take protective action. Participants were nonetheless not clear on whether reserving predictive FSMs for the rarest extreme events would meet community expectations.

The 2019–2020 season was a landmark not only in terms of the intensity and extent of fires, but also demands for and provision of information about them. Public criticism and official inquiries revealed some of the advantages and shortcomings of agency communications, and these in turn informed participants' responses regarding the benefits of predictive FSMs (e.g. RCNNDA, 2020; SAIR, 2020). For many, the expectation was that such a visual format 'caters to different learning styles' (Vic PI4) and 'could be shared quite easily because visually it's really easy to understand' (NSW PI1). One public information practitioner aptly captured this sentiment by supporting predictive FSMs on the basis that they would add to 'the arsenal of tools' used for warnings 'to meet the multiple and diverse requirements of the multiple and diverse audiences that we have is really very useful' (Fed PI1).

On this point, interviewees identified two interlinked benefits of using predictive FSMs. The first was that increases in hazards and demands for information about them has increased the need for agencies to produce warnings that can be 'easily' and 'quickly' broadcast. 'If it's a little light graphical product like that,' one participant stated, 'it can kind of go everywhere and really hopefully try and cut through a lot of different channels' (NSW PS2). Several described an apparent shift in public expectations of agency warnings, with some describing how 'the information age is well and truly here' (Qld IC1) and agencies now faced 'a whole new world' (Vic PI2) of public demand for visual information. During the 2019–2020 season, one public information practitioner stated, '[the public] were just drinking up everything that we could send out to them' (Fed PI3). Second, and relatedly, several interviewees were enthusiastic about the ability of visualisations and mobile platforms to enhance accessibility of warnings for audiences who are historically underserviced or hard-to-reach and therefore in greater hazard risk. As participants noted, these audiences include tourists, young people or 'the TikTok generation' (Qld-IC1), individuals with low written literacy, or culturally and linguistically diverse (CALD) communities. Agency awareness of these audiences makes it 'even more important … to be able to display stuff, you know, easily digestible visual way' (Tas PI1).

Complementary to public safety and information access benefits, some participants asserted that releasing predictive FSMs would likely increase the public credibility of emergency agencies. Trust in agencies is widely understood as key to individuals acting on their information (Garcia & Fearnley, 2012), and several participants felt that providing accurate and timely predictions would consolidate agencies' role as the trustworthy 'one-stop shop' for information. These products would, one public information practitioner (WA PI3) said:

> … help people understand that they can rely on the fire agencies to give them really good science-based information, timely information. That increases trust, that increases the foot traffic to rely on the fire agencies and not go elsewhere.

'It gives much more authority or reputational credibility to an organization … to provide the tools that [publics] need to know what's happening' (SA PI1). If agencies were trusted, an incident controller said, then members of the public 'have the confidence to act in the way that they're being asked to act' (Qld IC1). Nonetheless, while some felt that predictive FSMs would improve trust because they would 'improve transparency of information' (SA PI2), others expressed concerns that greater transparency could be a 'catch-22' with risks to agencies (see 4.2). 'Building trust with the public is probably a good benefit or an outcome out of this,' a predictive services practitioner noted, 'But that hinges on us getting [intelligence] right more than we get it wrong' (Vic PS1).

Discussions of the benefits of releasing predictive FSMs revealed widespread positive perceptions among practitioners. However, the potential benefits were rarely discussed in isolation and were routinely balanced with reflections on the contextual factors and potential risks discussed below.

4.2. Risks associated with releasing FSMs as a new public information product

The identified downside risks of releasing predictive FSMs publicly were numerous but can be analytically split between the public and agencies. Differences in individual participants' perceptions and prioritisation of risks seemed to reflect both experience and socio-institutional context, such that participants with more senior roles were often more sensitive and alert to institutional risks.

The primary public risk discussed by participants related to possible negative outcomes stemming from shortcomings in the production, communication, or dissemination of predictive FSMs during an emergency. Foremost these included technical errors and misinterpretation.[3] The first of these includes well-documented errors of data entry or platform glitches in emergency situations, including during the 2019–2020 wildfire season, when telecommunications networks and agency apps were sometimes unavailable or faulty. Several participants foresaw the utilisation of predictive FSMs as reinforcing existing dependencies on digital platforms (e.g. agency apps) and thereby posing risks to public safety:

> A lot of our systems require connectivity, telecommunications, and obviously that's one of the first things to go in major emergencies, and I don't think that our redundancies of getting the information to communities are good enough. (Vic-PI4)

Nonetheless, despite their certainty that technical errors would occur, many explicitly affirmed that the benefits far outweighed the risks. To mitigate these risks, and ensure information delivery during emergencies, agencies needed to complement the development of digital capabilities with low-tech redundancies (e.g. door-knocking, community noticeboards).

Participants felt the more significant public risks related to the potential for predictive FSMs to be misinterpreted. These misinterpretations could take several forms. First, participants were concerned that at-risk communities or individuals might view predictive maps as truths rather than estimates. As Neale and May (2018) describe, these predictions contain many uncertainties and emergency management professionals are encouraged to interpret them 'seriously not literally'; as a public information practitioner told us, '[the public] don't have that comprehension that it's a rough guide' of a likely outcome

(ACT PI1). Drawing on past experiences, some were uneasy about forecasts 'in really high-like sort of resolution' could lead to maladaptive behaviours such as, many noted, if individuals immediately outside the bounds of a fire's predicted spread would mistake their location for safety. Second, a majority held doubts about the ability of many members of the public to check important details on a predictive FSM during the stress of an emergency. What if a map was disseminated and individuals did not check if it was current? 'We'll end up with people relying on information that's incorrect and then they could put themselves at risk,' an incident controller said (QLD IC1). 'That's a risk, particularly, with social media,' one person noted, where 'because of the algorithm, they're not necessarily seeing the most up-to-date information' (VIC-PI-4).

These concerns, combined with more generalised apprehension about the possibility that predictive FSMs might 'confuse' or 'overwhelm' people, suggest a shared mythology of the public as fragile and easily confused. On the one hand, participants felt agencies risked losing the attention of public audiences through 'warning fatigue,' with some referring to what they observed to be a decrease in public protective action in response to frequent warnings over long periods. Interviewees widely identified that 'over-warning' could 'erode or dilute confidence in the warning system by turning it into white noise' (QLD PS1), presenting risks to public safety and agency credibility; creating a 'boy who cried wolf' scenario, wherein, if people are desensitised to warnings then '[that] puts the public in harm's way' (NSW PS1). On the other hand, participants also revealed common doubts about public audiences' abilities to interpret or sort information. Some have 'a lack of belief in the public's ability to consume some of these products and really thinking that they won't understand it' (NSW PI3). Providing more intelligence 'could really potentially be putting people in danger's way,' a public information practitioner said, 'because for some people, they're struggling to keep a tally on it all, as it is' (QLD PI1). The possibility of misinterpretation is endemic to public communication, and participants held diverse opinions about the severity of the risk posed to the public and extent to which it can be mitigated with clear communication and education campaigns.

The other significant type of risks posed by predictive FSMs, participants suggested, were risks to agencies (Begg et al., 2021). These were often couched as 'trade-offs' for the benefits to agency credibility and increased public trust discussed above, and included risks of legal, reputational, and political consequences. Amongst participants, there was a pervasive sense of the sector's 'risk aversion,' stemming from an understanding that 'fire [management] is the most scrutinised of the hazards' (SA IC2), with wildfire management agencies often facing criticism from official inquiries, politicians, new media, and others as well as litigation from members of the public. Some shared memories of 'fire services being beaten up over many decades with respect to inquiries and Royal Commissions and the like' (Tas PS1) or being 'burnt a few times historically from inquiries and inquests' (SA PS2), such that they feel 'firies are held to a higher standard of accountability around decision-making than other hazards' (SA PI1). Consequently, participants asserted agencies were wary of new expectations or demands being placed on them, such as needing to produce predictive FSMs. Agencies have 'anxiety about losing control of the message which is why,' one participant stated, 'some organisations don't like using social media that much' (Nat PI1).

More specifically, some participants stated that releasing predictive FSMs would increase the risk of legal consequences**,** such that agencies 'could get legal action

taken using these [maps]' if they were inaccurate (NSW PI3) or face 'possible litigation' for adverse outcomes even where the prediction was correct (Vic PI3). Alternatively, some others perceived legal risks in not publishing the predictive FSMs they already use in emergencies. To quote one striking response:

> It's really interesting when people go 'oh, they mightn't use it or might not understand it.' No, no, we understand it, we need to show it in such a way that they'll understand. Because if it came down to it and we're sitting in front of the coroner and they said, 'why did you make this decision?' 'Oh, because the [predictive FSM] said it was going to do this.' 'Well, did you communicate that with the public?' 'Oh, we tried to say in words and everything but–' 'Well, why would we just not show them this product?' We do this as though this is top secret … Why would we not show them the product? (NSW PI3)

Given the significant legal protections emergency services agencies have regarding the release of information about hazards (Eburn & Handmer, 2012), including warning polygons, the legal risks raised by participants may be more perceived than actual. If this is the case, then the widespread perception of legal risks may be a proxy for concerns about reputational damage and complaints affecting agencies and potentially even the careers and lives of individual practitioners.[4]

Noting the inherent uncertainty of fire prediction, practitioners expressed concerns that while accurate predictions could positively impact agency reputation, inaccurate predictions could negatively impact it. Predictions used by agencies are often geared towards lower-probability, high-impact outcomes, rather than highest likelihood, with the result that several participants were able to point to 'some doozy predictive maps over the years that didn't even get close to happening' (SA-IC2). Practitioners were therefore worried about 'developing mistrust,' as has happened sometimes within agencies (Neale, 2023), if existing forecasting practices were not adapted for the public. Perceived over-predictions 'from a community perspective [agencies] could be seen as issuing inaccurate information' (WA PI1), or as one incident controller noted: 'every time you put out a map that doesn't occur or it's out by enough then people start to question it' (SA IC2). Others spoke about how releasing FSMs 'can build trust but it can also break trust' (Tas PI1) or how 'there's a real risk there [of] the boy who cried wolf' (ACT PS1). 'The minute you get it wrong … people will go 'Oh well how can I trust you next time you show me one of these maps that shows half the State's going to burn?'' (Vic IC1).

A related reputational risk stemmed from concerns not about the quality and character of predictive FSMs but about agencies' capacities to produce, communicate, and disseminate them in a timely manner. Drawing on their experience in other domains of emergency management, participants highlighted wider issues of 'role creep' and under-resourced service demands leading to perceived shortfalls in service performance and delivery. That is, even a seemingly straightforward change in services, like publishing fire predictions, can have significant impacts on a range of roles that may already be working at capacity. Reflecting on the release of predictive FSMs in the 2019–2020 season, one predictive services practitioner recalled that:

> … there was significant trust placed in the fire agencies in releasing these predictions, and if we released them routinely, it would have – for us in New South Wales, in the way we prepare these predictions, it would have very significant resource implications for us, to make sure that we maintain that level of trust. (NSW PS1)

'I have reservations because of my experience from [2019-2020]' another predictive services practitioner said (ACT PS1), because 'once [the community] see a map people have questions.' Similarly, others described how the creation of a new warning product necessarily had flow-on effects, for example that 'it would create more workload' for public information practitioners who would be expected to 'decipher' this new kind of warning for others (WA PI1).

Finally, in considering risks to agencies, it is worth noting that some interviewees thought predictive FSMs could lead to political consequences for agencies. While explicit discussion of this matter was relatively rare, it was implied in several participants' discussions of other matters such as industry stakeholders' reactions to warning information along with a sense that 'political pressure has always been at the edge of fires' (NSW PI3) (see Buizer & Kurz, 2016). For example, three practitioners spoke about how the political importance of tourism and resource industries in fire prone regions could sometimes influence agency decision-making during emergencies (Tas IC1, Tas IC2, Vic PI1). The future release (or not) of predictive FSMs could therefore prove politically contentious if they were perceived to cause unnecessary disruption. A public information practitioner noted that 'it's a different risk politically, telling 100,000 tourists to leave an area … there's going to be political implications from that which is why we need to have a robust formula to determine whether or not we use this particular tool at that particular time' (NSW PI4). Like this interviewee, others also avowed that clear processes and guidelines could eliminate the risk of political pressure shaping agency decision-making, despite existing experience and evidence pointing to the contrary (see Neale, 2023).

In sum, the primary risks of making predictive FSMs public were seen to be risks to public safety, stemming from misinterpretation or misuse, and risks to agencies from possible legal, reputational, or political consequences. Alternatively, as a few interviewees noted, there could be legal, reputational, or political risks in withholding useful intelligence from the public. Two preliminary insights are worth noting. First, practitioners perceive risks to public safety and to agency credibility as intertwined if not co-produced. Second, practitioners understand attempts to increase public safety as innately risky to agency reputation. Consequently, given the risk aversion of emergency management agencies, there are arguably significant barriers to agencies releasing more information than their leadership feel they absolutely must.

4.3. Producing, communicating, and disseminating FSMs to the public: challenges

Here we highlight key barriers to the future production, communication and dissemination of predictive FSMs to the public, highlighting practitioners' insights into how these can be overcome. When asked directly about these barriers, interviewees' responses ranged across several topics relating to workflows, training, resourcing, education, role definition, platform requirements and more. For analytical purposes, however, these can be synthetically categorised in terms of specific domains: the public and operational control.[5]

As noted, many participants across all roles and jurisdictions articulated an understanding of the public as easily confused and possessing limited literacy about natural hazards, with many seeing this as the most significant challenge. Those involved in public

information roles contributed strongly on this topic, noting examples of community members having limited comprehension of existing warning products. As one participant noted, 'the community has a hard enough time dealing with the current fire danger rating system' (Tas PS1), while another thought that since 'the community doesn't understand our three levels of warnings.' Consequently, some felt that new products such as predictive FSMs 'could create a more dangerous situation' (WA IC2) by confusing community members further. Nonetheless, many participants who raised these concerns also felt that public education programs could enhance public understanding; predictive FSMs 'would need to be a pretty comprehensive education awareness raising campaign or strategy' (WA PI1), they noted, to 'educate the public on what they are and how to read them and what they mean basically' (Tas IC2). To this point, participants identified how a range of other warnings (e.g. warning polygons, thunderstorm risk maps, cyclone prediction maps) had been successfully integrated over time through a range of education strategies.

Alternatively, discussions of challenges relating to public use of warnings highlighted other issues within agencies. As one participant reflected, 'I think the one that makes me take a deep breath,' were FSMs to be released publicly, 'is actually the education piece of our own people' (SA IC1). Similarly, several participants noted that they felt agency staff had difficulty comprehending existing warning products, particularly the new Australian Fire Danger Rating System. 'I don't think, as a sector, we even truly understand it ourselves,' one interviewee said, 'so I don't know how the community understand it' (Vic PI4). Therefore, some suggested, the development and introduction of a new product – such as predictive FSMs for the public – could present an opportunity to improve training and education within agencies, improving internal understanding and awareness of the predictive maps that already circulate within emergency management. Incorporating greater agency participation into such a process would help ensure the predictive FSMs were 'fit-for-purpose' and help to mitigate risks of user error and misinterpretation as identified above. Further, as some suggested, agencies' development of guidelines in dissemination and communication of predictive FSMs could facilitate better sector confidence in these outputs and, thereby, the credibility of these outputs when they are released publicly.

While capacity to adopt novel technologies is dependent on context (Agyepong & Liang, 2023), interviewees offered different views of the challenges of integrating new warnings into incident control systems. These differences were clearly apparent not only between jurisdictions, but also between and within agencies, role type and locality, reflecting the different infrastructures, processes, platforms used by agencies across Australia. Nonetheless, lack of appropriate resourcing was widely and consistently identified as the primary challenge. Reflecting on future possibilities, participants often made indirect and explicit references to budget and resource limitations as the 'modus operandi' of fire management agencies, as one stated, 'resourcing is always an issue when you want to try and do something new' (Qld PS1). Several participants expressed beliefs that these were not insurmountable, suggesting public predictive FSMs are 'something that's achievable but it's just a matter of getting that resourcing' (NT IC1) or noting that 'the capability exists, it's really a funding question' (Fed PS1). However, participants from smaller jurisdictions with smaller revenue bases noted were less optimistic about the financial or practical feasibility of implementing new public information products. As

one South Australian IC commented, 'not [to be] a fire service crying poor but literally, we don't have any money' (SA IC1).

Further, participants were uncertain if there was currently sufficient capacity and training to support the work that making predictive FSMs public would require. Despite growing investment from agencies in predictive services over the past decade (Neale & May, 2018), interviewees in predictive services roles (e.g. Fire Behaviour Analysts or 'FBANs') highlighted that this has been counterbalanced or even outstripped by increasing demand for predictive services and their outputs within agencies. This is experienced, as one FBAN commented, as 'very low investment in our training and our preparedness' (WA PS1). Further, some expressed concerns about the future attractiveness or feasibility of the role in the future, highlighting what they viewed as an overall lack of skilled FBANs to meet existing demand, facilitated by a failure of agencies to adequately support clear and consistent skill and career development pathways for the FBAN role. Therefore, given the perceived current lack of training support and available staffing, it is unsurprising that participants felt this presented a significant challenge to any future expansion of predictive services outputs such as predictive FSMs. Committing to deliver a new product without the workforce capacity to do so consistently could, as some noted, present a significant reputational risk to agencies.

Participants provided several suggestions for how agencies might overcome these capacity challenges, though notably there was consensus that the case for greater resourcing and capacity-building for any new warning product – including predictive FSMs – could be strengthened significantly in two ways. First, in order to convince decision-makers of its necessity, it was important to clearly define the purpose of a new product. Second, it was important to establish national or interjurisdictional consistency in formats and triggers for the design and dissemination of FSMs as a public product, not only to minimise confusion but also to create collective buy-in. There were conflicting views on the practical feasibility of this kind of consistency, given the current inconsistent application of national warnings standards across jurisdictions and hazards, however those from smaller jurisdictions emphasised benefits of a coordinated approach for interstate and interagency sharing of resources, personnel, and lessons. Some participants with experience in developing national standards were cautious that the road to a national approach would not be straightforward. To quote one such participant, 'Good luck figuring that out' (Fed PI2). Overall, despite widespread suggestion from practitioners of the potential benefits and pathways to developing a nationally consistent product, our findings suggest standardisation remains slightly contentious, with many practitioners highlighting that the 'art' of predictive science requires flexibility and creativity (Alexander & Cruz, 2013; Neale & May, 2018; Owen et al., 2012).

5. Discussion and areas for future research

This study was conducted in a context of growing public enthusiasm for more detailed and timely warnings products, aligned with recommendations from recent public inquiries and developments in agencies' capacities to use predictive technologies in new contexts and novel ways. Despite the apparent inevitability of agencies releasing predictive FSMs to the public in the future, relatively little is known about how emergency management professionals perceive these products or how they envision their potential

dissemination to publics. This study's empirical investigations revealed a number of findings including an apparent contradiction: that despite study participants having both technological capability and a general willingness to release more intelligence to the public, they are presently reluctant to put this into practice. This article has examined the social, cultural and institutional factors underlying and sustaining this contradiction, and in doing so, demonstrates the importance of identifying and addressing these social and institutional barriers. Below we present a discussion of the implications of these findings for the implementation of public information and warning products and platforms in similar countries, and identify areas for future research.

Studies of emergency management agencies have highlighted social processes underlying the adoption of novel technologies and strategies, suggesting implementation is unlikely unless agency professionals support them (Hamilton et al., 2019; Walling & Vaneeckhaute, 2020). Among Australian practitioners, we found no evidence of outright opposition to the public release of predictive FSMs, with all participants identifying potential benefits to agencies and public safety (Begg et al., 2021; Whittaker et al., 2021). However, despite some convergence in practitioners' views of 'ideal' ways of making predictive FSMs for the public, practitioners expressed concerns about the success of future implementation. In contrast to agencies' public enthusiasm for implementing technical solutions, and despite having the technical capability to release predictive FSMs, participants highlighted a need for significant cultural and institutional change for them to feel supported and willing to adopt this practice. As suggested by several of our participants, social and institutional factors such as risk aversion determine the adoption of new warning products and platforms more than technical feasibility. This further supports the long-refuted idea that the use and evaluation of predictive technologies by decision makers is value-free and driven by innovation (Hamilton et al., 2019; Neale & May, 2018). Ultimately, our findings support further studies to understand the contexts surrounding professionals' use and adoption of novel technologies including within warning systems (Walling & Vaneeckhaute, 2020)

In interviews, questions about warnings led to many practitioners reflecting on observed shifts in public expectations of agencies in terms of information provision, particularly after the 2019–2020 Black Summer season (see RCNNDA, 2020). As they highlighted, to realise the perceived benefits of providing more information to publics, such as predictive intelligence, also meant stoking 'unrealistic' (WA IC2; NSW IC1) expectations among publics about the level of service they should expect from agencies during emergencies. In other words, it may be unsustainable to always respond to increased public expectations with more products and services. A related tension is evident in participants' support for greater transparency of information with publics, alongside their awareness that agencies are called upon to maintain or 'perform' control during emergencies (Neale, 2023). In an increasingly fiery and uncertain future, cultural change may be needed for agencies to re-imagine their role in delivering information to publics during emergencies. Ultimately, we echo Whittaker et al.'s (2021) suggestion that managing public expectations will be an important and ongoing challenge for agencies.

As well as illustrating participants' assumptions about the publics they serve, practitioners' views of the risks of publics misinterpreting predictive FSMs revealed a knowledge gap regarding whether these are actual risks. Subsequently, we contend there are

two key opportunities for future research to support agencies implementation of this novel strategy. First, we suggest that there is a need for collaborative research to better understand the diverse needs of the public for predictive intelligence and, further, to determine appropriate design and communication of predictive FSMs. Some participants were optimistic that the recent development and accessibility of novel predictive technologies presents an opportunity for agencies to test different visual and textual features of map designs. Further, research could contribute evidence-based guidelines for consistent and clear messaging accompanying maps to communicate uncertainty and actions to take, which practitioners widely noted as critical for mitigating the risk of misinterpretation. Subsequent research in this project aims to investigate how members of the community understand, receive and respond to predictive information (Morrison et al., 2024). Similar research can support the implementation and adoption of new predictive technologies and strategies with other natural hazards warning systems in Australia and in other fireprone countries.

Second, our study suggests that perceived public education gaps and inconsistent understanding of predictive FSMs among agency personnel present both challenges and opportunities for agencies. Most interviewees asserted public education and awareness campaigns should be an important accompaniment to the release of all new warnings products. However, existing studies into professionals' perspectives on and uses of predictive technologies within emergency management agencies suggest that an information-deficit approach to education and training provision will not necessarily translate into effective implementation of predictive public information products either within operational decision-making or public warnings. Rather, a range of other social factors such as trust, credibility and risk tolerance influence the way predictive products are adopted and used by agencies, publics, and others (e.g. news media, politicians). Therefore, alongside internal and external educational efforts, agencies should consider ways to foster trust and social connection between predictive intelligence professionals and their various audiences (Neale et al., 2021). This will, we suggest, support improvements in the reputation, comprehension, and use of predictive intelligence in decision-making, warnings systems, and beyond.

6. Conclusion

Through a qualitative study of emergency management professionals, we have investigated their views regarding current and potential future uses of predictive fire spread maps (FSMs) by emergency management agencies in Australia. Our findings indicate that these professionals generally support the release of predictive FSMs to the public, but they also identify a range of benefits, risks, and barriers to achieving this end. These include not only risks to the public, but also risks to practitioners, agencies, and governments, as well as the cultural barriers of institutional conservatism or risk-aversion. This study is part of a larger research project that will expand on these findings through several empirical studies of how members of the public in different Australian states and territories interpret and act on predictive FSMs in order to provide agencies and others with evidence-based guidance.[6] One of these studies, for example, suggests that members of the public may question the trustworthiness and credibility of if they are not considered sufficiently timely or seem inconsistent with other information sources (Morrison et al., 2024).

The research presented in this article has several implications for future research, policy, and practice in natural hazards management in Australia and internationally. First, our findings underscore that the release of predictive FSMs to the public is not simply a matter of technical feasibility but also a matter of social and institutional factors, including the values, beliefs, and risk tolerances of emergency management professionals. Second, our research suggests that the successful implementation of predictive FSMs will also depend on the building and maintenance of trust between key parties, including between agencies and publics as well as between emergency management professionals. Third, our research highlights the importance of considering the cultural and institutional context of emergency management agencies when implementing new technologies. This requires understanding the values, beliefs, and risk tolerances of the professionals who work in these agencies, as well as the organisational structures and processes that shape their decision-making. Overall, our findings suggest that the successful implementation of predictive FSMs will require a collaborative effort between emergency management agencies, researchers, and the public. By working together, we can ensure that this technology is used in a way that benefits the public and helps to reduce the impacts of wildfires.

Notes

1. This project was reviewed and approved by the Deakin University Human Research Ethics Committee (ref: HAE-22-020). Participants were provided with a Plain Language Statement and Consent Form prior to their interviews. All participants gave written consent to take part in this research project.
2. It is worth nothing that there is an extensive scholarly literature that calls into question the existence of any significant causal link between risk awareness and action due to the wide range of empirical evidence of an 'awareness-action gap' (see Eriksen & Gill, 2010; Scolobig et al., 2015; Lindell & Perry, 2012).
3. Several participants were concerned about the potential malicious misuse of predictive FSMs by individuals seeking to mislead others during an emergency. While they could not give examples of this happening previously with established warning products (e.g., warning polygons) they were nonetheless concerned about the possibility.
4. The reputational risks posed to individual practitioners by the production of predictive FSMs were not a topic of discussion with participants, though other studies suggest that individuals' careers can be affected by the reception of their previous predictive outputs (see Neale, 2023; Neale et al., 2021).
5. Participants also identified many technical barriers and challenges relating to the current lack of agreed processes, platforms, and formats for publicly released predictive FSMs. These varied in their details between jurisdictions, given that each jurisdiction has different processes for producing, communicating and disseminating other hazard information. Ultimately, we could find no examples of participants contending that such issues would present unresolvable challenges if agencies committed to produce predictive FSMs for public release.
6. See the 'Predictions in Public' project website: https://www.naturalhazards.com.au/predictions-in-public.

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