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**Information needs across stages of volcanic activity for effective decision-making:
A Ruapehu scenario, Aotearoa New Zealand**

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Abstract (250 words)

Effective decision-making before, during, and after volcanic activity relies on relevant, timely, credible, and actionable information. Our study examined the information requirements of publics, agencies, and Māori partners, across a spectrum of volcanic activity in Aotearoa New Zealand. Using a qualitative research design (focus groups, interviews), discussions were conducted with participants based on a hypothetical Ruapehu scenario, an active and frequently monitored cone volcano. The scenario comprised four stages of volcanic activity over several months: (1) quiescence/low unrest, (2) moderate to heightened unrest, (3) small to moderate eruptions, and (4) post-eruption.

Participants identified information needed to support decision-making at each stage. Several information categories were critical across all stages, including current volcanic activity, risks and impacts, recommended protective actions, and sources of further information. However, other needs evolved as activity intensified. During quiescence, participants prioritised situational awareness and preparedness. As conditions shifted to unrest, demand increased for information on precursors, forecasts, and locations at risk to support anticipatory planning and readiness. During eruption, information about impacts, consequences, and response options became critical. These needs continued post-eruption, alongside information to support recovery and management of longer-term impacts.

Findings demonstrate that volcano information needs are dynamic and stage dependent, requiring communication approaches that adapt as situations evolve. To support effective decision-making, agencies should develop proactive information strategies that anticipate evolving public and organisational requirements. Recommendations include tailoring information to audience contexts, providing plain-language and action-oriented content, avoiding information overload, preparing communication templates in advance, evaluating products, and strengthening agency and community relationships.

Keywords

Volcano, information, communication, decision-making, Ruapehu, New Zealand

1.0 Introduction

Relevant, timely and usable information assists with effective decision-making about volcanoes by agencies and publics. The information required differs, depending on the location and type of volcano, its likely hazards and risks, past eruptive or unrest experience, and the context in which people are making decisions (e.g. agencies making decisions about managing an emergency or protecting infrastructure, versus decision-making by publics). Additionally, differing types of information are also required across various phases and stages of volcanic activity (Perry & Lindell, 2018; Todesco et al., 2022), from before a volcano erupts (quiescence), through unrest, eruption, and post-eruption (Figure 1). Consequently, because of these variables and uncertainties, volcano information provision and communication can be challenging (Fearnley, 2022; Fearnley et al., 2018; Solana et al., 2017).

Illustrative volcano event scenarios and stages

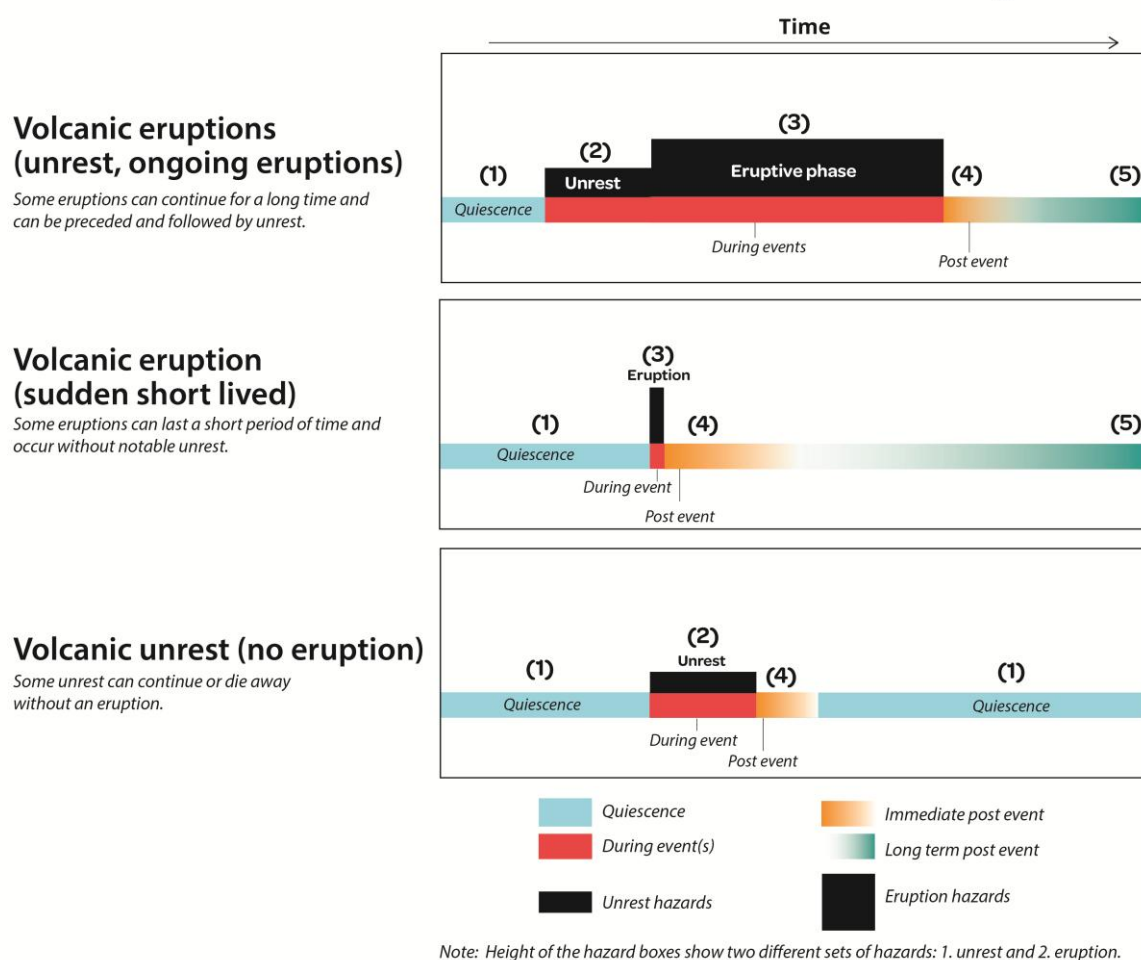


Figure 1. Examples of different stages of volcanic activity for three different scenarios: volcanic eruptions with unrest and ongoing eruptions; a sudden short-lived eruption; and volcanic unrest with no eruption (modified from Das et al., 2025).

Regarding information provision across different phases and stages in New Zealand (henceforth referred to as “stages”), Das et al. (2025) has highlighted several gaps. Namely, information provided during quiescence and eruption is well documented in the literature; however, less is written about information provision for unrest particularly during stand-alone periods when activity escalates but deescalates again, and for post-eruption situations.

The abundance of literature in New Zealand about volcano information during quiescence is due to efforts undertaken to develop scenarios for planning, exercises, and educational outreach activities (Das et al., 2025; Doyle & Johnston, 2011; Lowenstern et al., 2022). Documentation of information during and immediately after eruptive episodes has also been prevalent, for example for the 1995/96 Ruapehu and 2012 Tongariro eruptions (Johnston et al., 2000; Jolley et al., 2014; Paton et al., 1998; Paton et al., 1999). The overseas literature mirrors the New Zealand situation where there is better reporting of outreach and planning efforts when a volcano is quiet, and a multitude of papers on communication during eruptive episodes (e.g. Garcia & Mendez-Fajury, 2018; Graham et al., 2022; Herfianto et al., 2022; Hufstetler et al., 2026; Stovell, et al., 2022; Newhall et al., 2018; Solana et al., 2017).

Regarding unrest and post-eruption stages in New Zealand, while some recent stand-alone unrest events (e.g. Ruapehu 2022; Taupo 2022-23; Whakaari 2024) and post-eruption periods (post 1995/96 Ruapehu; Whakaari, 2019) have occurred, these have been less documented in terms of formal literature (Das et al., 2025). Again, international literature is also less extensive on these topics, with less examples of communication during unrest events that do not lead to eruption (e.g. Anzieta et al., 2021; Hill et al., 2017; Peers et al., 2020; Coombs et al., 2026) and relatively few reports on extended post-eruption periods (e.g. Córdoba Hernández et al., 2026; Newhall & Solidum, 2018). Additionally, across the literature there is scant commentary on how information transitions across different stages from quiescence to post-eruption, as volcanic activity escalates or deescalates. A patchy understanding of information types and needs over such stages is problematic as it limits the ability of science agencies and other information providers to lean on insights that help deliver appropriate, meaningful, timely and evolving information that assists with effective decision making.

To address the knowledge gap about types of information needed across different stages of volcanic activity, we undertook a research project aimed at better understanding information and decision-making needs from quiescence through to post-eruption. This research used focus groups and interviews to investigate agency, public, and Indigenous (i.e., Māori Iwi, hapū and organisational) perspectives and information requirements for stages of volcanic activity. In this way we sought to capture the voices of these participants to help inform the future planning, development and delivery of volcano-related information, particularly via science monitoring agencies and Volcano Observatories. While the research context is

Aotearoa New Zealand, the findings have relevance for other jurisdictions with similar communication needs during volcanic episodes.

2.0 Method

2.1 Context for volcanic activity and information provision in New Zealand

Aotearoa New Zealand comprises three primary volcano types (Wilson et al., 1995): cone volcanoes (e.g. Taranaki, Ngauruhoe, Whakaari) active calderas (Taupo and Okataina) and the Auckland volcanic field (Figure 2). Also offshore, are active cone and caldera volcanoes (e.g. Raoul Island Caldera, Monowai, and Rumble III cones) (GNS Science, 2026). Active volcanoes are closely monitored for activity (Miller & Jolly, 2014). Over the past 200 years of recorded history, unrest and eruptions have occurred at differing volcanoes generating various hazards, and creating impacts on people, infrastructure, and the environment (Becker et al., 2001; Hickling et al., 1999; Johnston et al., 2000; Newnham et al., 2010; Potter et al., 2015; Zanini & Bennett, 2024). Table 1, adapted from Das et al. (2025), outlines major volcanic events that have taken place in recent history.

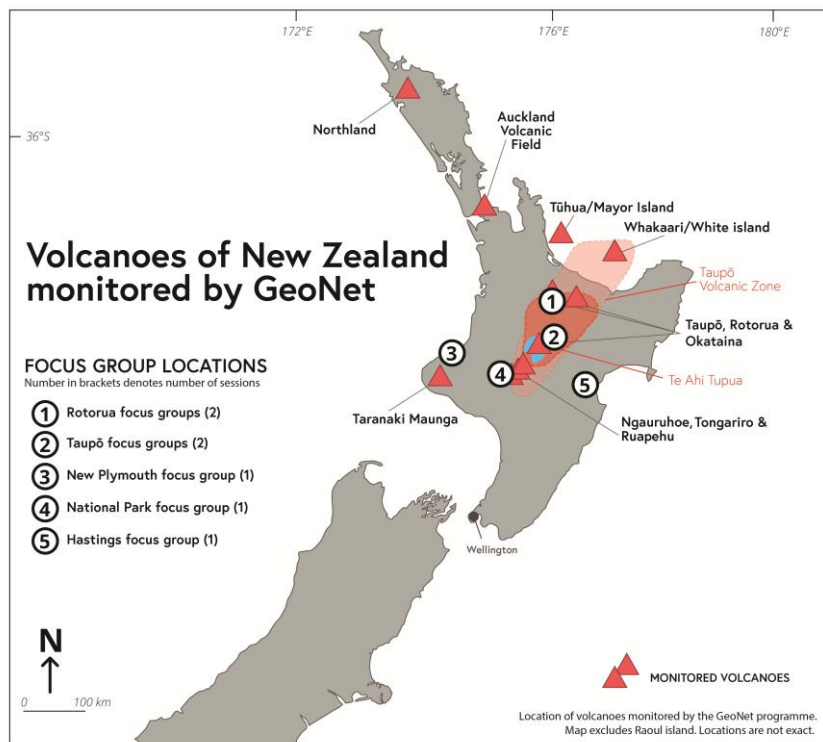


Figure 2. Location of New Zealand’s monitored volcanoes and volcanic centres or fields – shown are Northland (Bay of Islands - Kaikohe Volcanic Field, Whangarei Volcanic Field), Auckland Volcanic Field, Tūhua Mayor Island, Whakaari White Island, Okataina Volcanic Centre, Rotorua Caldera and Maroa Volcanic Centre, Taupō Volcanic Centre, Tongariro Volcanic Centre (including Tongariro, Ngauruhoe, and Ruapehu), and Taranaki Maunga, (modified from Das et al., 2025).

Table 1. Summary of major eruptions, incidents, and impacts in New Zealand recorded over the last two hundred years. Other minor and less impactful unrest and eruptive events have also been recorded, including eruptions from Ruapehu in 1969 and 2007, Tongariro in 1896-97 and 1975, Ngauruhoe in 1954/55, 1974/75 and 1977, Whakaari/White Island from the 1960s, and unrest in Taupō from 1983 onwards (modified from Das et al., 2025).

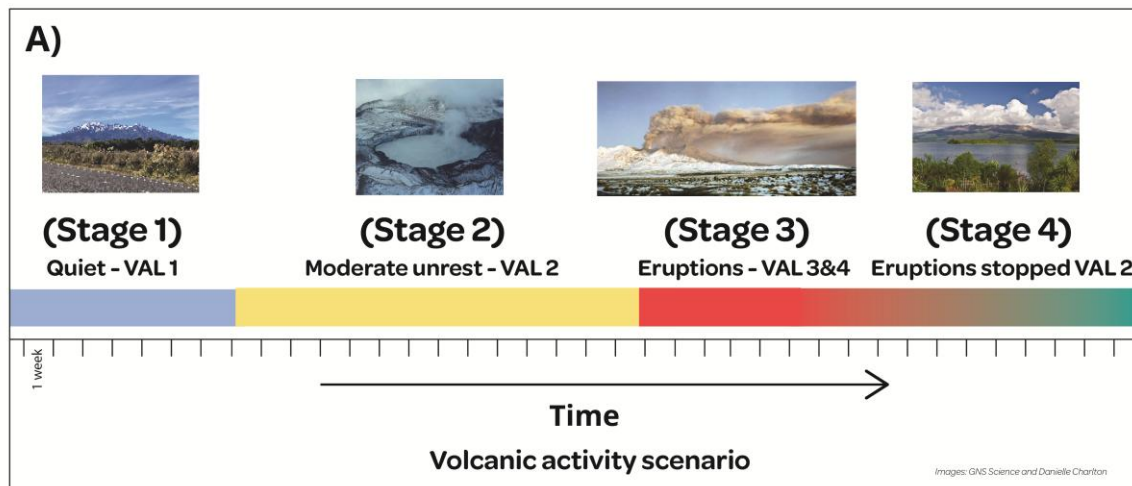
Volcanic activity/incident	Event type and impacts
Whakaari/White Island eruption, 2019	Explosive eruption, claimed 22 lives, impact on tourism, economic costs to organize rescue operations and compensation claims (Baker et al., 2022).
Te Maari Craters eruptions, Tongariro Volcanic Centre, 2012	Series of eruptions. Ash emissions. Small lahar near eruption site. Damaged sections of the Tongariro Alpine Crossing walk, affected vegetation. No fatalities reported (Department of Conservation, 2012).
Ruapehu eruptions, 1995/96	Major eruptions causing ashfalls, lahar, and pyroclastic fall deposits, damaging infrastructure (e.g. roads, electricity), and disrupting local economy, tourism, agriculture. No reported casualties. Economic costs of ~130 million NZD (Johnston et al., 2000).
Tangiwai disaster, caused by lahar, 1953	A lahar triggered by Ruapehu crater lake wall collapse destroyed a railway bridge and caused a passenger train to derail. 151 persons were killed (Johnston et al., 2000).
Ruapehu eruptions, 1945	Eruption and ashfall, lasted months, impact on agriculture, water, and electricity, no casualties reported (Johnston et al., 2000).
Whakaari/White Island eruption, 1914	Explosive eruption and lahar, claimed 10 lives (Kilgour et al., 2021).
Tarawera eruption, 1886	Massive eruption near Rotorua, estimated to kill about 120 people and caused significant economic losses (Rowe et al., 2021).

In New Zealand, Earth Sciences New Zealand (ESNZ - previously known as GNS Science) is responsible for providing scientific and technical information about volcanoes (Department of the Prime Minister and Cabinet, 2015), with the GeoNet project a source of ongoing monitoring information (Potter et al., 2018). Volcanic alert levels (VALs) are provided via GeoNet across all stages of volcanic activity (e.g., Potter et al. 2014; 2018). Other information is actively produced and disseminated by ESNZ as needed (e.g. website information, Volcanic Activity Bulletins (VABs), news stories, video updates (GNS Science, 2024)). Other agencies also play a role in information provision including: national, regional and local emergency management agencies who are responsible for preparedness, response and recovery information; Department of Conservation (DoC) who manage volcanic risks within conservation areas; MetService and Civil Aviation Authority (CAA) who are

concerned with volcanic ash and aircraft operations; Indigenous Māori entities including iwi and hapū who have jurisdiction over particular volcanic areas; and sector agencies such as health and infrastructure who manage volcanic impacts on people and the environment (Das et al, 2025).

2.1 Method details

For our study we wanted to explore information needs across different stages of volcanic activity. To do this, we developed a volcanic activity scenario for the active cone volcano, Ruapehu, and based focus group discussions and interviews around that scenario. ‘Scenario’, in this study is defined as a hypothetical series of stages through time. Ruapehu was chosen due to past knowledge about the 1995/96 eruptive episode (Table 1), and the availability of existing scenario information for the volcano. The scenario developed for this research is a shortened (and simplified) version of the Johnston (1997) scenario. The scenario covers a period of a few months during which Ruapehu volcano undergoes four different scenario stages: 1. Quiescence or low unrest (VAL 1), which Ruapehu commonly sits at, i.e., Business as Usual (BAU); 2. Moderate to heightened unrest (VAL 2); 3. Small to moderate eruptions (VALs 3-4); and 4. Post-eruption (VAL 2) (Figure 3). It is worth noting that these stages are not directly transferable to other volcanoes, e.g. VAL 1 at Auckland Volcano Field, Taupō, or Taranaki would not be regarded as ‘quiescence’, and therefore the specific scenario used for this study should not be applied directly to other contexts.



B)

2. Scenario

Stage 1: Quiet time/VAL1

"Activity at Ruapehu volcano is relatively quiet (minor unrest)"

Monitoring information:

- No notable activity
- Lake temperature stable
- **Volcanic Alert Level 1 and Aviation colour code is green**

Communications:

- Periodic Volcanic activity bulletin releases from GeoNet
- Basic news releases and social media posts

Timing: around late October

Figure 3. A) Timeline of the Ruapehu scenario used for the focus groups and interview, showing Stages 1 to 4. B) Example of information provided to participants for Stage 1 (Quiet time/VAL 1). Full information on the scenario can be found in (Becker et al., 2024).

Using the scenario, seven focus group sessions and one interview (Table 2) were conducted in five locations (Figure 2) from 16 May to 28 August 2023. The location of National Park (Waimarino, Manawatū-Whanganui region) was chosen as one focus group setting due to its close proximity to the active central North Island cone volcanoes. Taupō, Rotorua (Bay of Plenty region), New Plymouth (Taranaki region) and Hastings (Hawkes' Bay region) were selected as they could be impacted by ashfall from Ruapehu.

A total of 79 people participated. Where focus group sessions were well-attended, facilitators divided participants into smaller sub-groups to assist with discussions. Thirty participants were public citizens from Rotorua and Taupo, who attended focus groups in their local library and leisure centre meeting rooms. The remainder were decision makers from agencies (49), whose roles related to local and national and regional emergency management,

emergency response (e.g. Police, FENZ), public information, science communication, education and research (including those with science/volcano backgrounds, and outdoor education), infrastructure, health, insurance, media, conservation/land management, and those with formal organisational roles that were also affiliated to Iwi or hapū. Agency focus groups were held in council offices in New Plymouth, National Park and Hastings. In two cases focus groups were held after volcano advisory group meetings (i.e. Taranaki Seismic and Volcanic Advisory Group (TSVAG) in New Plymouth, and Central Plateau Volcanic Advisory Group (CPVAG) in National Park). The sole interview was conducted online via video conferencing software.

Table 2. Summary of focus group participants

Location	Time and date	Focus group / interview	Publics / agency	Number of participants	Number of sub-groups	Group codes (assigned to quotes)
Rotorua (Bay of Plenty)	10:00, 16 May 2023	Focus group	Publics	6	2	RAM1, RAM2, RPM1
	18.30, 16 May 2023	Focus group	Publics	2	1	
Taupo (Bay of Plenty)	10:00, 17 May 2023	Focus group	Publics	10	3	TAM1, TAM2, TAM3, TPM1, TPM2, TPM3
	18:30, 17 May 2023	Focus group	Publics	12	3	
New Plymouth (Taranaki)	13:00, 25 May 2023	Focus group	Agency	24	5	TK1, TK2, TK3, TK4, TK5, M1
	13:00, 22 Aug 2023	Interview	Agency	1	1	
National Park (Manawatu-Wanganui)	14:00, 4 July 2023	Focus group	Agency	18	4	NP1, NP2, NP3, NP4
Hastings (Hawke's Bay)	14:00, 28 Aug 2023	Focus group	Agency	6	1	HB1
Total				79*	20	

* Variations in the number of participants in the reporting of results (Section 3.0 onwards) are because not all participants answered every question.

In both the focus group discussions and interview, we started with an ice breaker question, asking participants about their experiences with volcanoes or volcanic activity, which they discussed in small groupings.

Following the icebreaker question, participants were then presented the four different stages of the Ruapehu activity scenario sequentially (i.e., Stage 1: quiescence/low unrest, Stage 2: moderate to heightened volcanic unrest; Stage 3: small to moderate eruptions; Stage 4: post eruption). For each stage, we first provided written details summarising the stage, including volcano monitoring information (e.g. seismic activity, Crater Lake changes, erupted material), as well as information that might be provided by GeoNet (e.g. VALs, Volcanic Activity Bulletins (VABs), media interviews, or ashfall forecasts) (GeoNet, nd). Where possible, written details were also supported by photographic images or video clips to help people visualise what might be happening at a particular phase of the volcanic activity (for example, we used videos about unrest during Stage 2, and clips from the 1995/96 Ruapehu eruptions for Stage 3).

After participants had been presented the details about a particular stage, we asked them to consider the following three questions: -

1. How concerned are you about volcanic activity from Ruapehu affecting you and your regular activities?
2. How important is information about volcanic activity to you and your organisation at this stage?
3. What type of information is important to you/your organisation at this stage?

For Questions 1 and 2 the whole room of participants were asked to individually rate their concern on a 5-point Likert scale. For the Question 1 the scale included: Not at all concerned (1), Slightly concerned (2), Somewhat concerned (3), Moderately concerned (4), Extremely concerned (5). For Question 2 the scale was similar and included: Not at all important (1), Slightly important (2), Somewhat important (3), Moderately important (4), Extremely important (5). Data from these questions was collated and analysed quantitatively for each stage of activity. Basic frequency data is reported in the results. No significance tests were performed on the data due to the low sample size.

To answer Question 3, focus group participants were asked to undertake a card sorting exercise in their smaller sub-groupings (Figure 4). Card sorting is a mixed methods research technique that helps a group to collaboratively organize content hierarchically (Hagemann et al., 2007). Sub-group participants were asked to sort topics of information into whether they thought the information was ‘critical’, ‘nice to have’ or ‘not needed’ for each stage of volcanic activity of the scenario. A set of topics pre-written on cards was provided for sorting (Table 3), but participants were also encouraged to add any topics that they felt were

missing on blank cards. Once participants had sorted their cards, photographs were taken of each stage as a record, and these were used later to quantitatively identify the type and numbers of topics considered ‘critical’, ‘nice to have’ or ‘not needed’ across each stage. In this way it was possible to understand what were deemed critical pieces of volcano information at each stage of activity, and how it might differ for each focus group location. The sole interviewee did not formally participate in a card sorting exercise but was instead asked to comment on the types of information they considered critical across the four stages. The focus group and interview discussions were audio recorded, and later transcribed for analysis.



Figure 4. Volcano information card sorting exercise from publics Taupō focus group (Photo: Manomita Das, used with permission from participants).

Table 3. Pre-written information topics on the cards given to participants for sorting.

What are the precursors to an eruption? What is the volcano is doing now? What will the volcano do next? What are all the things the volcano could do next? Explanation of what might be causing activity What are the different hazards-processes? Maximum area that could be affected by an eruption What are/could be the impacted areas? How much danger are we in? Would this affect other volcanoes? What has happened in the past?	How might volcanic activity affect us? How might volcanic activity affect travel? How might volcanic activity affect the economy? How might volcanic activity affect the environment? How might volcanic activity affect the agriculture sector? How might volcanic activity affect infrastructure? How might volcanic activity affect health? What do we need to do? Where do we get more information?
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Data from the card sorting exercise were analysed quantitatively for each stage of volcanic activity. Basic frequency data are reported in the results. As this was an activity performed collaboratively by sub-groups, we recorded if one sub-group had assigned the topic into a category (i.e. critical, nice to have, not needed) at each stage. We then collated and combined these results to identify which topics were deemed critical across stages 1-4. If at least one sub-group from each of the five locations deemed a certain topic critical, then we ascribed it the highest rating of a 5; vice versa if only one sub-group from one location deemed a topic critical, it received a rating of 1. More information about the card sorting analysis can be found in section 3.5.1.

Transcriptions from the recorded discussions were qualitatively analysed via an inductive coding process (Lyhne et al., 2025), and data from the coding organised into volcanic activity stages as per the Ruapehu scenario to help understand why participants were concerned or thought certain types of information were important or critical at certain stages.

2.2 Background context

During our study in 2023, Ruapehu was at its usual status of VAL 1 and Taupo was slightly elevated, having gone from VAL 0 to 1 in 2022. The previous year (during March-July 2022) Ruapehu had also experienced a period of heightened unrest (VAL 2). The fatal Whakaari/White Island eruption had occurred in December 2019 and was still on people's minds. Additionally, Cyclone Gabrielle and other severe weather events had impacted the

North Island during January and February of 2023, causing devastating flooding, landslides, and 11 deaths. All these events had some influence on participants' thought processes and responses as reflected in the data collected. This is highlighted in the next section which briefly reflects on participants' experience of volcanoes captured during the icebreaker.

2.2.1 Context related to participants' experience

Public participants who participated in the Rotorua and Taupō focus groups had a higher level of experience with volcanoes compared with most publics. Common experiences discussed in the focus groups included living through the 1995/96 Ruapehu eruption episode, experiencing the Taupō (2022/23) and Ruapehu (2022) unrest periods, study of science or geology, recreating on volcanoes, or prior work in a professional capacity related to volcanoes (e.g., park management, recreation, health, emergency management, defence). Consequently, we interpret that our public participants generally had more capacity to understand and interpret volcano information, and assess the risk posed by volcanoes, than might be expected of NZ publics more broadly.

Participants from agencies had a variety of experiences. Some had extensive training in understanding volcanoes and how to respond to eruptive activity, worked in day-to-day roles which involved a component of volcano planning, or had lived through events like Ruapehu 1995/96. There was an overall high level of experience of people responding to past volcano events, with many having worked on previous Ruapehu eruptions, lahar and unrest episodes (particularly from the National Park group), or were involved in responding to the 2019 Whakaari eruption. However, there were also some agency participants whose experiences were restricted mostly to recreating on volcanoes, especially where volcanoes were not a core part of their working role. Like public participants, we generally interpret that those from agencies also had a higher level of understanding about volcano information.

3.0 Results

First, we identify the sources and channels of information mentioned by participants in their discussions, to provide some context for where participants anticipated their information would come from (Section 3.1). This is followed by a section on participants' perspectives of important information characteristics in general (3.2). Then we present quantitative results regarding participants' concern about the four stages of activity for the Ruapehu scenario (Section 3.3), and the importance of information across these stages (3.4). Finally, we use the qualitative data to analyse concern, critical information needs and actions across the four stages of volcanic activity, highlighting how these might evolve over time (3.5).

3.1 Sources and channels

We did not specifically ask participants to identify the sources and channels they used, or anticipated using, to get volcano information, or what types of information they needed from each. Therefore, we did not collate an exhaustive list of sources and channels. However, if any sources or channels were mentioned during discussions we coded and analysed these. Those that were mentioned by participants are listed together as follows.

In general, we found that publics were heavily reliant on GeoNet, alongside other public sources or channels of information (e.g., Civil Defence Emergency Management (CDEM), Emergency Mobile Alerts (EMA), Department of Conservation, visitor centres, organisations such as Natural Hazards Commission Toka Tū Ake (NHC¹), educational institutions, media, social media, Iwi/hapū, friends/family). Participants were additionally likely to draw on past experience as a source of information.

Agencies also relied heavily on GeoNet or GNS Science (i.e. ESNZ) and the sources and channels listed above for publics, but alongside further information from relevant sectoral organisations (e.g., infrastructure, lifelines, government agencies, etc.). For agencies, it was noted that relationships were key to obtaining information, and agencies would often make direct contact to obtain intel, as a participant from Hawke's Bay described regarding obtaining science advice: "*When we start having issues can we call them at nine o'clock at night? Are they going to answer their phones?*" (HB1). In New Zealand there is 24/7 on-call capability related to the GeoNet volcano monitoring function.

It was interesting to note that agencies volunteered twice as many sources or channels as publics (approx. 30 versus 15), highlighting the need to consider differences in who might provide information, and via which channel, when considering publics vs agencies.

¹ At the time of the research known as Toka Tū Ake EQC (Earthquake Commission).

3.2 Important information characteristics

Before discussing our findings regarding concern, information importance, and critical information needs across the four stages of the Ruapehu scenario, we touch briefly on general information characteristics that participants considered important, based on the qualitative data from discussions. These characteristics aligned across both publics and agencies. Table 4 lists the characteristics that were mentioned, with representative quotes alongside.

Briefly, participants wanted clear, simple and actionable advice, from credible and trusted sources and channels, ensuring that there was consistency across these. Information provision needed to be timely, regular and sustained, but also ensure it evolved over time as volcano activity changes. Contextual aspects (e.g., volcanic context, people receiving the information, location of recipients, prior experiences, indigenous perspectives) were important to consider so that a diversity of fit-for-purpose information could be developed and personalised for different audiences. It was suggested that a careful balance of content was needed to ensure information was accurate but framed in ways that it did not scare and overwhelm audiences. Collaborative input into information development was deemed useful and important.

Table 4. Important characteristics of volcano information highlighted by both publics and agency participants

Communication characteristics	Example quote
<u>Context is important</u> Consideration of context (e.g., volcanic context, people receiving the information, location of recipients, prior experiences, indigenous perspectives) was considered important for understanding how to develop information content and deciding how this information might be delivered (i.e., via sources and channels).	<i>“It’s also important that GeoNet or GNS or whoever it is, couches any of its messaging in context. An example would be, say, the VAL [...] gets bumped up... Well, it’s important for them to note that this is pretty typical normal behaviour for the volcano. This regularly happens. Because they need to bear in mind that, you know, there might be an [in]experienced [person...] that might get this bulletin and misinterpret it as a pretty significant development” (M1).</i> <i>“[Information on]...the impacts on the things like the environment and the agriculture, and, you know, those types of things are probably a little bit dependant on your context, so where you live, where you work” (TPM2).</i>
<u>Clear communication</u> Clear communication was requested.	<i>“...you just need real, clear facts at [Stage 3]. We just need real, clear, concise messaging.” (TPM3)</i> <i>“clear and accurate summary of the situation” (M1)</i> <i>“...really clear actions”, dependent on location, extent and exposure (TK3).</i>
<u>Credible</u> Credible sources were important. Credibility included knowing that the source had some expertise in the subject area.	<i>“[It’s] not just the type of information. It’s the credibility of the information” (TK3).</i> <i>“...if it’s a person or a or an organisation that I consider to be the expert in the field, so if [...] it’s a volcanic alert from GeoNet I’ll pay attention” (HB1).</i>
<u>Consistent</u> Consistency from the same source/channel was considered important, as well as across multiple sources.	<i>“And I think the messaging should probably be consistent across it at all levels. It’s just as you go up it becomes more detailed and more frequently updated, but you still need to know the same things...” (TPM3).</i>
<u>Trusted</u> Mostly mentioned in relation to the importance of being able to trust the source and/or channel of the information. People also discussed how trust might be affected by uncertainty in information, changes in information, or perceptions agencies are holding back information.	<i>“Interviewee 1: That’s what I said before about can I trust that? Where do I get that? Interviewee 2: Are you a trusted source?” (TPM2).</i> <i>“Would you trust that they were going to say actually, it’s okay if you stay where you are. Everything’s fine. We don’t expect anything to happen and because part of disaster management is not to upset the [...] people so everybody just doesn’t pack up the roads or panic buy [...], so I would be asking are they down playing [...] how serious it is ‘cos they don’t want to create panic...” (TPM2).</i>
<u>Simple, basic, summarized</u> Many wanted simple or basic information, already summarised by science or other responding agencies.	<i>“...simple, basic script [...] so that it’s stuff that we can actually quote to people, you know, and not to have people not listen because we then try and use scientific terms and then they’re like, ‘what does that mean?’, and we’re like, ‘I don’t know’” (HB1).</i>

<u>Concise messages/advice</u> In addition to simple/basic information, there was a specific request for concise information or messaging (similar to National Emergency Management Agency's (NEMA) consistent messaging, or messages like "Drop, Cover and Hold for earthquake shaking).	<i>"...basically clear, concise information about what's happening, what's changed, what's prompted the alert level change, along with that background context, basically to help the public kind of apply some perspective to it" (M1).</i> <i>"I think there should be a basic package of information, like, you know, when there's, when you can't see five... in front of your face wear a mask, stay inside. Protect your water. Cover your car." (TPM1)</i>
<u>Action oriented</u> The inclusion of messages that tell people what they need to do for different stages of volcanic activity.	<i>"I'd want to know what we needed to do if we're getting told what could happen here" (TK4).</i> <i>"What do we need to do? This needs to be really clear actions, and that's going to depend on location. (TK3)</i>
<u>Multiple sources and channels</u> Multiple sources and channels of volcano information were considered necessary (ensuring consistency as noted above).	<i>"...we want certain things from the likes of GNS and we expect other stuff to be coming out from MBIE, Waka Kotahi" (NP2).</i>
<u>Layered, or linked information</u> Providing summary information, but also the ability to dig into more detail if needed (e.g., through extra layers/links to further information).	<i>"Having those dot points at the top and then the report at the bottom, 'cos you still get those people who want to read a report and then you're covering all of your bases" (HB1).</i>
<u>Diverse information</u> Considering different audiences' needs and having a range of information available to meet those needs.	<i>"[The information needed] depends on the audience, so we're dealing with a completely different audience. You're thinking about how you can manage the response and recovery and plan, and like I'm thinking about what are the immediate questions that my community is going to ask of us, and who can I point them to, and how do we tell them that?" (TK4).</i> <i>"... 'cos if you're immobile, old, who don't have smart phones and they don't have landlines and they're not online. In a situation like this in the context, how do you get information? (RAM2).</i>
<u>Incorporating indigenous knowledge & practices</u> Considering how to best communicate with indigenous peoples (i.e. tangata whenua/mana whenua); how tangata whenua/mana whenua might 'monitor' activity themselves and communicate it; and partnerships regarding communication and management of impacts.	<i>"We talk about the phenomena that creates the hazard, not necessarily the volcano itself. It's not an issue if there's nothing there [...] I don't look at it and go oh yeah, that's a volcano" (TK3).</i> <i>"...so we have representatives from all marae that come together in all situations like this [...] at VALI we'd do this. At 2 you'd do this in their world. It might be a little bit different to how everybody else might do it..." (TAM2).</i>

<u>Timely</u> Prompt and frequent updates, particularly if activity is evolving.	<i>"...there's a pretty critical need for us [the media] to be able to relay that information onto the public and we need to have information that is as timely and as accurate as possible" (M1).</i>
<u>Regular</u> Regular updates, depending on the timeframe (e.g. might be less regular during quiescence, more so as activity escalates)	<i>"...[a] volcanic eruption can occur at any time, so I think it's best that we have regular [...] up-to-date knowledge of what the status is" (TK1)</i>
<u>Repetitive</u> The need to continue to repeat information over time, so people are reminded of what's happening and what to do.	<i>"So, some of this information we're going to be sharing the whole time because the need [for].... different user groups to get it" (TK5).</i>
<u>Evolves</u> Information that evolves and is updated across stages and/or circumstances to account for the changing context.	<i>"Yeah [...] has any of it changed, 'cos following an eruption presumably you might decide that next time the lahars are going go this way because of what happened....so you have to redo all of your work..." (NP1)</i>
<u>Sustained</u> Ensuring engagement with information is sustained over time, to keep it in people's minds, and prompt actions they need to take.	<i>"It's an interesting thing, aye, because like with volcanoes they're sort of spread out over such a long time and the initial alert comes in and then it's almost like it's still doing its thing but it we've forgotten about it [...] so how do you keep that engagement going with members of the public?" (TK1).</i>
<u>Balanced</u> Accurate, but doesn't scare or cause anxiety.	<i>"It's an interesting balance, isn't it, 'cos you don't want scare people [...] by constantly reminding them [at Stage 1] that it could erupt any day, but at the same time you want them to have thought about it enough to think 'what am I going to do about it?' so that you've got some chance that they're prepared and they're going to do the right thing..." (NP1).</i> <i>"Should be being fed relevant information that [is] useful and practical" and "regularly", "without panicking people" (TPM1).</i>
<u>Confirmatory information</u> People might seek additional information for confirmation or self-reassurance, especially when activity changes.	<i>"Yeah, [the public] will ask [is this going to affect any other volcanoes], and we'll want to say, no you dumb arse, and then we'll go, we'll second guess ourselves and go.. Shit, we'd better ask that question. Oh, we'll ring up [a scientist] and like just double check [...]. Is our one connected?" (TK4)</i>
<u>Personalised information</u> Personalisation makes information more relevant for people, can provide an emotional connection, increase	<i>"Interviewee 1: How might the volcanic activity affect me? I guess that's kind of good to know, right? Interviewee 2: I reckon that would be pretty critical. Interviewee 1: It affects your planning doesn't it.</i>

trust in the information, and can prompt people to take relevant actions.	<i>Interviewee 2: Yeah. Do I get in my car? Should I have filled it up last night?” (TPM 2).</i>
<u>Collaborative</u> The importance of relationships and a collaborative approach to communication and decision-making before, during and after volcanic activity (e.g. with Treaty partners, between agencies, with media, etc).	Regarding information and decision-making at Stage 4 post-eruption: <i>“I would suspect would be a major conversation, like a conversation with high level treaty partners and Government Ministers right across the board, seeking massive lots of information and input from everyone else as to what the decision would look like and the timeline for that” (NP2).</i>

3.3 Concern about volcanic activity for different stages

Concern about volcanic activity is useful as it can prompt information searching, further engagement with information, or undertaking actions to reduce risk (Becker et al., 2012). As reported in the methods section, we asked participants to rate their levels of concern for each stage of activity for our Ruapehu scenario. Overall, participants' concern levels were low during (Stage 1) quiescence, with 60% stating they were not concerned during this stage and only 33% slightly concerned (Figure 4). During unrest (Stage 2), concern levels rose, with the majority saying they were slightly and somewhat concerned (34% and 31% respectively). Overall, concern levels peaked at the eruption stage with 89% of participants stating they would be either moderately or extremely concerned about volcanic activity. Relatively soon after the eruptions had stopped, concern levels dropped, but stayed higher than they were during the unrest stage of the scenario.

Concern throughout the different volcanic activity stages

Percentage of participant responses (n=75-77)

	Not at all concerned	Slightly concerned	Somewhat concerned	Moderately concerned	Extremely concerned
Stage 1: Quiescence	60.00	33.00	7.00	0.00	0.00
Stage 2: Unrest	8.00	34.00	31.00	27.00	1.00
Stage 3: Eruptions	0.00	4.00	7.00	49.00	40.00
Stage 4: Post eruptions	16.00	19.00	28.00	32.00	19.00

Category ■ Higher % ■ Lower %

Figure 4. Categorical heatmap of level of concern across all participants (n=75-77, depending on the scenario stage) and percentages of total by scenario stage.

Concern levels by region

Stage 3: Small-Moderate eruptions

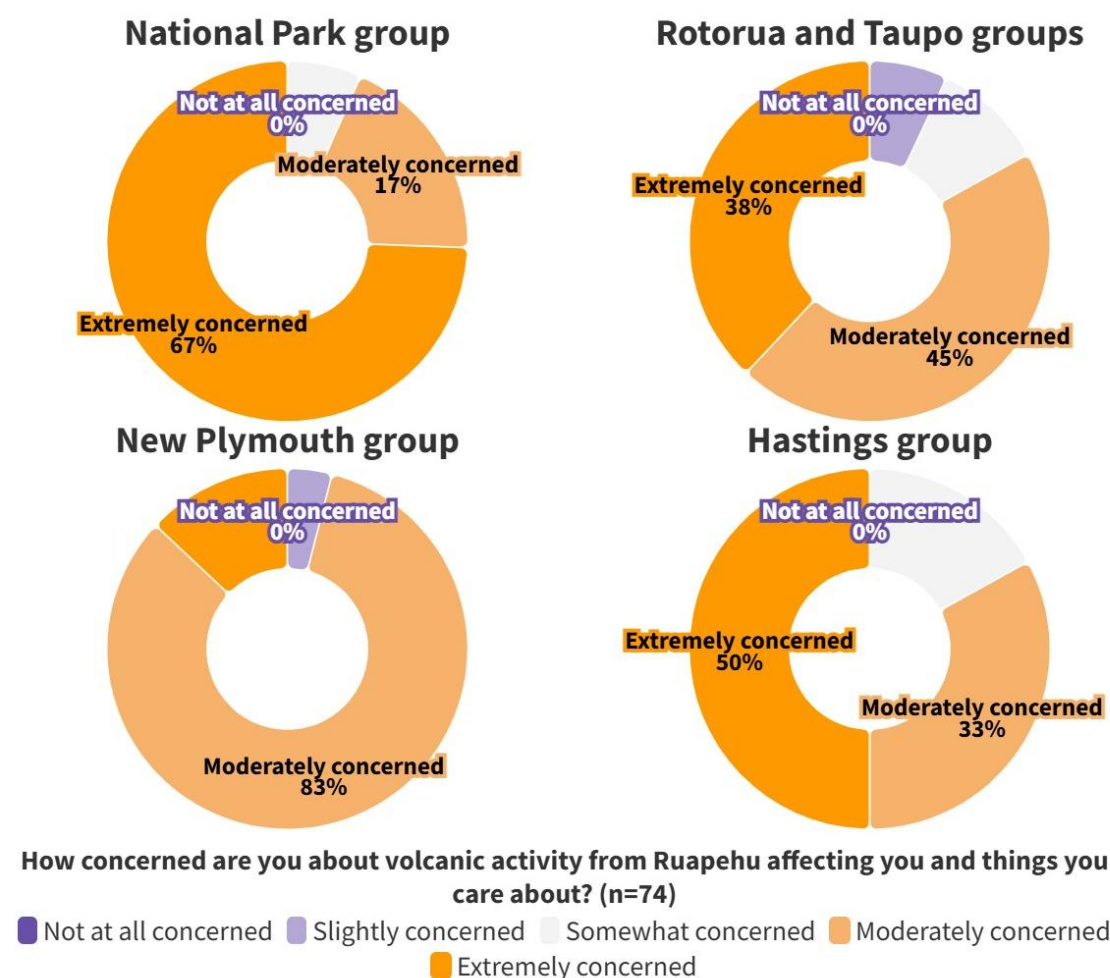


Figure 5. Breakdown of level of concern by region for scenario Stage 3 (small to moderate eruptions) across all participants (n=74). (National Park n = 16, Rotorua/Taupō n = 29, New Plymouth n = 23, Hastings n = 6).

Levels of concern were influenced by the location of participants. Those living, working or recreating in regions closer to Ruapehu tended to express higher levels of concern, as depicted in Figure 5 for the Stage 3 scenario eruptions. Higher levels of concern were also expressed by those who had responsibilities for others in the vicinity of Ruapehu, such as children, iwi or hapū, visitors/manuhiri (e.g. such as tourists), or employees. A Taupō-based focus group participant elaborated on how location influenced concern when comparing those living in the location of Taupō (80 km in a direct line from Ruapehu) versus Turangi (40 km):

“You’ve also got the context of geography as well. I mean Turangi obviously might be a little more worried about how [...] current volcanic [activity] might affect them, whereas at its low level in Taupō - it’s a little lower in my concern...” (TPM2).

People's past experiences could also elevate or lower their concerns, dependent on the context of the experience. For example, experience of Ruapehu 1995/96 was described by one participant as "terrifying" (TAM1), which then caused them to be concerned for future events; or alternatively another person expressed lower levels of concern based on previous experience of Ruapehu, "because I understand the scale of an eruption and I'm not too worried about Ruapehu in particular" (TPM2). In another example, concern could also be caused by a lack of experience as described by one person whose daughter-in-law worries when she visits Taupō:

"...we've a daughter in law who's is Australian, [...] if they come here and she sees that volcanic activity is anything above zero she gets concerned, because she hasn't got our experience, but she still has to stay here for a period of time, and that makes her anxious" (TAM2).

Provision of information was noted to reduce concern, as it helped with a sense of control and empowerment, as mentioned by a member of the public from TAM2: "...you feel like you're in control, right, and you can make decisions based on the information and you've got agency over choices." In terms of one specific information type, several people stated that knowing the volcanoes are being monitored reduces their worry and concern. There was discussion that the monitoring system was trusted to pick up any changes that could then be relayed to publics and agencies through Volcanic Alert Levels:

"I quite like the Volcanic Alert System. I feel like of all the disasters you can choose to live with in New Zealand, for me volcanoes feel the less scary because they're monitored, like they are so well monitored in New Zealand" (TAM1).

Concern also tended to rise when people were uncertain about what a volcano would do, or they were unsure what the impacts from activity might be. These uncertainties are discussed more in section 3.5 when the evolution of information needs across scenario Stages 1 to 4 are elaborated upon in detail.

3.4 The importance of information at different scenario stages of volcanic activity

In addition to concern, we also explored how important participants perceived information to be at the different scenario stages of volcanic activity for Ruapehu. During Stage 1 (quiescence), perceived levels of the importance of information varied widely from slightly to extremely important. The variation likely arose due to different types of information being

considered, and the differences in how publics or agencies might use that information. For example, agencies thought that volcano information at scenario Stage 1 for preparedness, planning and public education purposes was very important, and this was supported by publics who also perceived this as valuable, showing some consistency across participants in perceived importance. Another example, though, highlights variation in perceived importance of information. Many agency participants were supportive of receiving information related to updates on background monitoring and VALs at scenario Stage 1 because “[a]...volcanic eruption can occur at any time, so I think it’s best that we have regular [...] up-to-date knowledge of what the status is” (TK1).

In contrast, publics were not as interested in overly frequent updates for Ruapehu during quiescence, as long as they knew where to find the information (e.g., knew they could go to the GeoNet website [<https://www.geonet.org.nz/>] or app). They cited information overload concerns, and the potential for too much information to cause anxiety: “It builds anxiety. It builds anxiety that's not necessary” (TPM1). A participant from TPM2 also provided similar comments suggesting that, “I think when it’s, like there's nothing happening [...] I don’t need any extra things stressing me out, [...] I don't want to know about it right now”.

All participants did reiterate however, that they would want to know about any significant changes in volcanic activity and wanted status updates at these critical points in time:

“...if it was a day-to-day status report coming out that the volcano’s at Alert Level 1, I don't really care, because if it’s at Level 1 then it’s the status quo. I want to know when it shifts to Level 3 and there's a possibility of eruption” (TK1).

Importance of information throughout the different volcanic activity stages

Percentage of participant responses (n=74-6)

	Not at all Important	Slightly Important	Somewhat important	Moderately Important	Extremely Important
Stage 1: Quiescence	3.00	18.00	26.00	33.00	20.00
Stage 2: Unrest	0.00	4.00	13.00	49.00	33.00
Stage 3: Eruptions	0.00	0.00	1.00	7.00	92.00
Stage 4: Post eruptions	1.00	1.00	5.00	41.00	51.00

Category ■ Higher % ■ Lower %

Figure 6. Categorical heatmap of the importance of information across all participants (n=74-6) and percentages of total by scenario stage.

From scenario Stage 2 (unrest) onwards, both publics' and agencies' perceived importance of information increased. This peaked at the eruption stage and stayed high post eruption (Figure 6). The increased interest in information from Stages 2 to 4 highlights the surge in demand that may be expected when a volcano goes into unrest, then eruption, which is sustained over time through to the post-eruption period. When looking at the results from each region, the importance of information varied, with locations closer to Ruapehu rating the importance of information slightly higher than those further afield (Figure 7).

Importance of volcanic information by region

Stage 2: Moderate - Heightened unrest

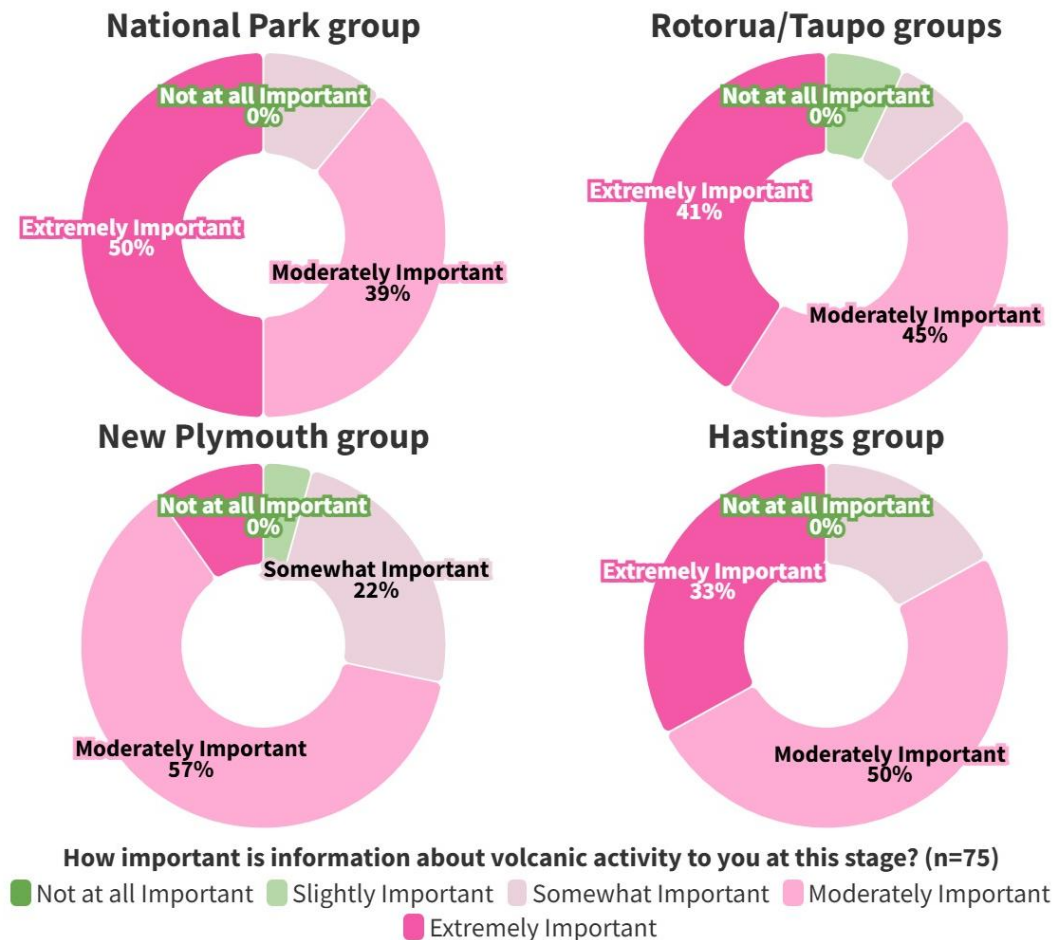


Figure 7. Breakdown of level of importance by region for Stage 2 (unrest) across all participants (n=75). (National Park n = 18, Rotorua/Taupō n = 29, New Plymouth n = 21, Hastings n = 6).

3.5 Concern, information needs and actions across stages of volcano activity

For this final section, we draw upon the card sorting exercise, combined with the focus group and interview discussions, to consider levels of concern in more depth, identify specific pieces of information participants found critical at each scenario stage and why, and investigate people's intended actions at different stages of the scenario.

3.5.1 Critical information at each stage (card sorting exercise)

First, we present the quantitative card sorting results of critical pieces of information for Stages 1 to 4. We examined how many different topics of information participants selected

by criticality and stage, including the 20 topics we provided them, alongside self-suggested topics. The number of different topics of critical information rose and became more diverse throughout the scenario, and peaked post-eruption with 75 different topics (Figure 8). The graph highlights the intense demand for differing types of critical information as activity at a volcano escalates, through to post-eruption.

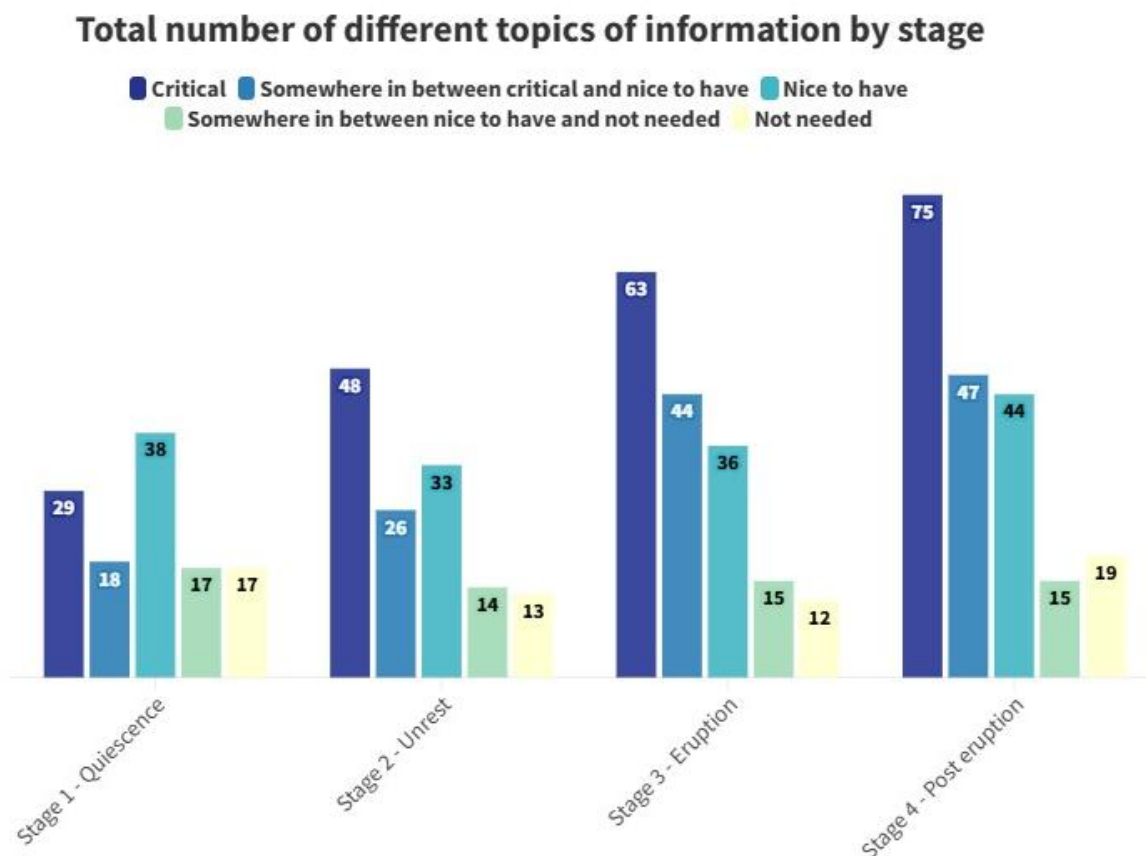


Figure 8. The total number of different topics of information divided by scenario stage (including topics supplied by us and self-suggested topics), with all groups and regions combined.

Table 5 shows the results from the card sorting exercise organised by scenario stage, information topic and level of importance (critical to not needed). Table 5 only presents the topics provided by the researchers; self-suggested topics were not incorporated into the analysis, primarily because upon examination they represented detailed elaborations on critical information already captured by the existing topics. Numbers alongside each topic indicate whether at least one sub-group for a focus group location (i.e., Rotorua, Taupō, New Plymouth, National Park or Hastings) thought that a topic was critical, somewhere in between critical and nice to have, nice to have, somewhere in between nice to have and not needed, or

not needed. Figure 9 provides a graphical summary, and highlights which topics were considered critical by at least one sub-group in all five locations.

The data reveal that some information is considered critical across all scenario stages (1-4), including: ‘What is the volcano doing now?’; ‘What are the precursors to an eruption?’; and ‘Where do we get more information?’. At Stage 1, in addition to these topics, also considered important were precursor information, and information about what to do during quiescence (e.g., plan and prepare).

As activity escalates into volcanic unrest (Stage 2), alongside the information required at Stage 1 listed above, information about areas at risk and the actions that need to be taken become critical. Forecasts (‘What will the volcano do next?’), information about hazards-processes, and information about potential impacts, were also mentioned by four out of the five focus group locations as critical during Stage 2.

During Stage 3 of eruptions, critical information notably increases. Most of the information required during Stage 1 and 2 is also required here, but information about impacts become elevated in importance, through to the post-eruption phase. Context is important to consider, however, as some agency participants reiterated that impact information for their sector was also key at Stages 1 and 2 where planning and preparedness might take place.

In Stage 4, when eruptions have stopped, critical topic areas reduce somewhat, with the most important information being on the volcano’s status, impacts, and actions needed. However, as mentioned previously, more elaborate and detailed questions arise under those broader topic areas, which accounts for increased information demands (e.g. questions related to ongoing hazard processes like ash remobilisation, and clean-up). Interestingly, participants also indicated they wanted to know more about what the volcano had done in the past, to provide context for how the volcano might respond in future (e.g. whether it might reactivate).

Table 5. Results from the card sort exercise with the data from all focus group locations combined (i.e., a 5 in the first cell of the table for “What is the volcano doing now?” for scenario Stage 1 “Critical” indicates that there was at least one sub-group that deemed this information critical from all five focus group locations of Rotorua, Taupo, New Plymouth, National Park and Hastings; while a 3 in the third cell of scenario Stage 1 “Nice to have” indicates that there was at least one sub-group that deemed “What is the volcano doing now?” information “nice to have” from only three of the focus group locations).

	Stage 1 – Quiescence/BAU					Stage 2 – Moderate unrest					Stage 3 - Eruptions					Stage 4 - Post eruption				
	Critical	In between	Nice to have	In between	Not needed	Critical	In between	Nice to have	In between	Not needed	Critical	In between	Nice to have	In between	Not needed	Critical	In between	Nice to have	In between	Not needed
What is the volcano doing now?	5	0	3	1	0	5	3	1	0	0	5	2	1	0	0	5	2	1	0	0
What are all the things the volcano could do next?	3	1	5	0	1	4	3	3	0	0	5	2	1	0	1	4	3	3	1	0
What will the volcano do next	3	2	5	0	0	4	3	0	0	0	5	3	1	0	0	4	2	0	0	1
Explanation of what might be causing activity	1	2	3	1	1	4	3	5	0	1	4	1	4	1	2	1	0	3	1	5
What are the precursors to an eruption?	5	2	4	0	1	5	2	2	0	0	3	1	2	2	4	3	1	3	1	5
What has happened in the past?	2	2	4	1	3	3	2	4	3	1	3	4	2	1	3	5	2	3	0	3
Would this affect other volcanoes?	0	1	5	1	4	0	4	5	3	2	4	3	3	2	2	0	1	4	3	4
How might volcanic activity affect us?	3	1	3	1	1	4	2	4	0	0	4	3	2	1	1	4	2	3	1	2
How might volcanic activity affect health?	2	1	4	2	2	4	1	4	2	2	5	2	1	0	0	4	4	2	0	1
How might volcanic activity affect the economy	1	0	2	1	5	1	0	3	2	4	3	2	4	1	1	3	3	4	1	2

How might volcanic activity affect infrastructure?	2	0	5	2	3	3	1	5	2	2	5	1	2	1	0	5	2	4	1	0
How might volcanic activity affect travel	4	2	3	1	4	4	0	4	1	2	4	2	3	1	0	2	3	5	1	1
How might volcanic activity affect the environment?	1	1	4	2	3	3	0	4	4	2	4	3	3	3	1	5	3	3	1	1
How might volcanic activity affect agriculture?	2	0	3	3	4	3	0	3	2	4	4	2	3	1	1	4	3	4	1	3
What are/could be the impacted areas?	3	1	3	2	2	4	3	4	0	0	5	4	1	0	0	4	1	4	2	1
Where do we get more information?	5	1	2	0	0	5	2	1	0	0	5	3	0	0	0	5	1	3	0	0
What do we need to do?	4	1	3	1	3	5	0	4	0	1	5	1	2	0	0	5	2	3	0	0
How much danger are we in?	4	2	3	1	2	4	3	4	1	1	5	3	1	0	2	4	2	4	0	1
Maximum area that could be affected by an eruption?	3	2	3	1	2	5	3	3	1	1	5	2	3	0	1	3	2	4	2	1
What are the different hazards-processes?	3	2	4	0	2	4	4	3	0	2	5	2	3	1	0	4	3	4	1	0

Critical information at each stage (as defined by every focus group location)

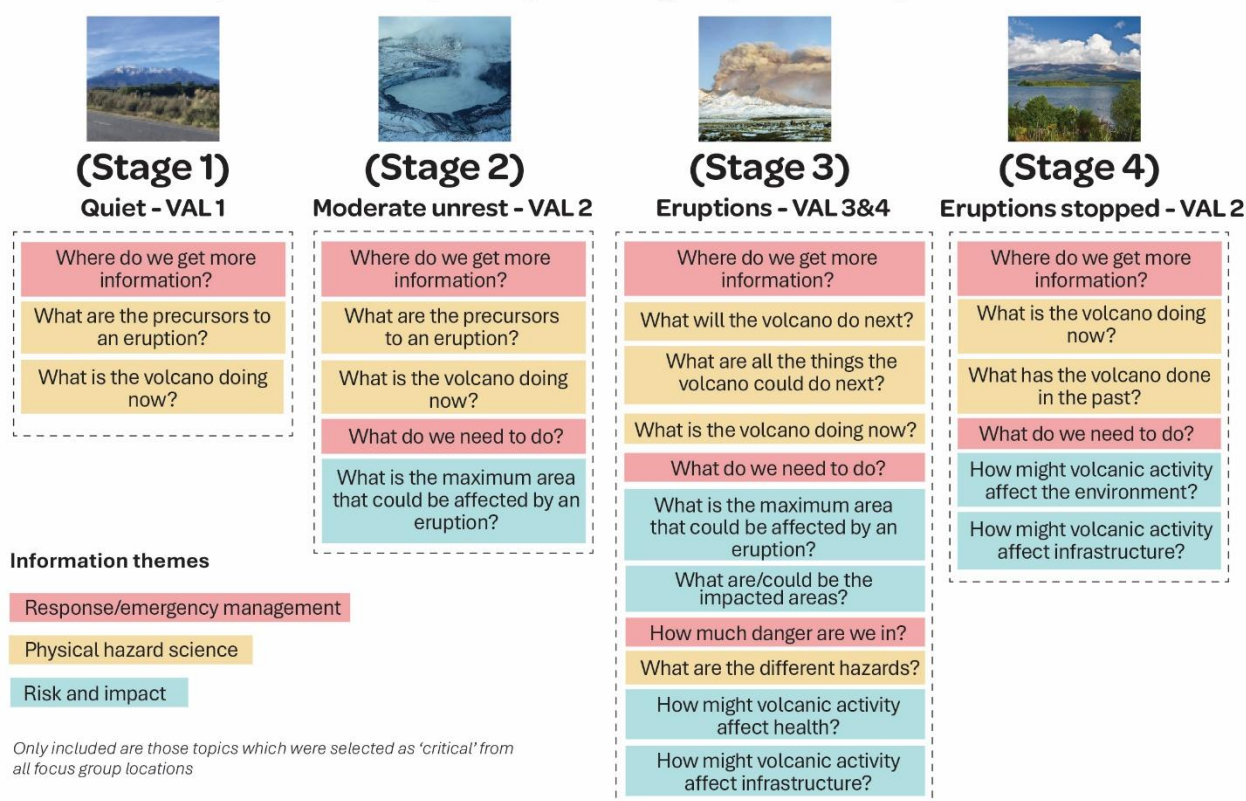


Figure 9. Critical information needs at each scenario stage, where at least one sub-group from all five of the focus group locations decided that certain topics provided by the researchers were critical (analysis excluded self-selected topics). Topics are colour coded into thematic categories of response/emergency management, physical hazard science, risk and impact.

3.5.2 Concern, information needs and actions (qualitative discussion data)

Here we summarise the focus group and interview discussion data to provide more context on what drove people's concerns, their perceived critical information needs and the actions they thought they would take across different stages of the Ruapehu scenario (Table 6).

3.5.2.1 Scenario Stage 1: Quiescence/BAU (VAL 1)

At stage 1 (VAL 1), those with higher levels of concern thought that activity could occur any time, or they had a role or responsibility that might be needed in an event. However, in general most people expressed lower levels of concern, due to Ruapehu having no obvious activity. Lower levels of concern were also linked to knowledge that the volcano was being monitored, and anticipation that participants would receive a notification or warning if something changed, as reported by M1:

“I’ve been [...] covering Ruapehu [in the media] for about ten years and I’ve seen, you know, Crater Lake temperatures go up and down. [...] So yeah, I’d probably be not at all concerned until GeoNet [...] started, you know, changing, and I guess, changing the language or changing the VAL” (M1).

Regarding information requirements, in the first instance many agreed that basic background information about volcanoes, volcanic impacts and preparedness was required for education, preparedness, and planning efforts:

“...what would be nice to have would be like evergreen resources that explain, you know, the sort of long-term picture of, [...] how the volcano functions, or the Crater Lake specifically, you know, how scientists continue to monitor it and how they basically look for changes in it, and just giving people, I guess, more kind of context. [...] A classic example would be, you know, like a video that GeoNet or GNS could basically make and provide that, [...] can always be used in any story about an alert level change of the volcano” (M1).

Regarding Ruapehu’s activity status at VAL 1, many publics and agency participants wanted to only receive minimal information to reduce information overload, and avoid concern, anxiety, or complacency issues. However, they were adamant that they needed the ability to find further information if required. This is summed up in a quote by a participant from HB1 who said, *“Where do we get more information? I think that’s critical, all the time, every time”*.

Some publics and agency participants also suggested that they ‘actively monitored’ Ruapehu, which constituted keeping a regular eye on background activity and incorporating this information into their decision-making and actions. This was described by a member of the public (TAM3) and a National Park agency participant (NP1):

“We actually [...] had the page open as part of our [internet] tabs, so it’s similar to the weather, so we look at the weather implications, and we also look at the hazards, like the environmental impacts so we have like the river levels, the volcano.... volcanic alert levels, so we just, we keep monitoring it, so I guess again, like it’s the awareness and making sure it stays in people’s heads” (TAM3).

“We have [in the] morning, a meeting, we set our day up, and the volcanic level and what’s happening with the volcano is part of our evaluation every day [...] Basically looking at the alert level....” (NP1).

Despite not wanting a lot of information about Ruapehu’s status in stage 1, participants did want to be directly informed if changes in activity occurred. Additionally, agencies highlighted that this was the stage at which relationship building should take place (before

unrest or eruption occurs) and suggested that information should support the important work of building relationships between responding personnel before an event.

3.5.2.2 Scenario Stage 2: Moderate to heightened unrest emerged (VAL 2)

At scenario stage 2 when there was an increase from moderate to heightened unrest (VAL 2), some participants' concerns became elevated due to uncertainty about what the volcano would do next, an awareness of their own roles and responsibilities in responding to volcanoes, and reflection upon experiences of past volcanic events where there had been impacts or poor outcomes. Alternatively, others expressed lower levels of concern compared to other participants at the same stage, as there were no obvious impacts to be seen.

At this stage people wanted more frequent updates and detailed information. Participants suggested they would switch to more proactive information seeking and would look to a wider range of sources to help gain intel about what was happening, confirmation of information, and reassurance. Agencies also described how their messaging might evolve from Stage 1 to 2 as more detail was required:

“...so our messaging to start with would be quite broad, quite generic, and then it changes tone when there's events, like if we went to alert level two this is how it would affect the travel, [these are] things you need to start putting in your kit...” (TK5).

With a greater hunger for information at Stage 2, content was likely to also be reworked or redistributed – thus introducing changes in the information itself, complexity in the flow of information, and an increased potential for misinformation.

“...we might get the facts from the powers that be and you know that that information's correct, factual, but then how we display it depending on audience. That's where it starts to slightly change a little bit” (TK3).

Tension did exist between those who wanted more information, and those that wanted less information, as the latter considered that information overload could potentially cause anxiety. Concerns about information overload were more likely to come from publics than agencies at Stage 2 and beyond.

Information considered useful by participants during unrest included basic scientific information about the volcano's status, what was causing the activity (as long as it wasn't too technical), changes in monitoring data over time, forecasts to gain an understanding of what the volcano might do next, geographic areas that might be impacted, any unfolding impacts (e.g. earthquake impacts from the unrest, societal impacts) and potential impacts in future. Participants suggested that information at stage 2 was required to support preparedness and planning for publics and agencies, as well as support relationship building and any functions that might need to be stood-up by agencies (e.g. Public Information Management function).

“So I’d be putting my planning hat on now.... Hey guys, we need to pay more attention, it’s the priority of the day, ‘cos it could happen” (TK1).

“You might drag out that volcanic plan you did in 1995 when all of that stuff started happening, when it last blew up, and you might go actually, we better brush this off and review this plan now, if you can find one. If you can't find one then you'll create one” (TK1).

3.5.2.3 Scenario Stage 3: Small to moderate eruptions at stage 3 (VAL 3-4)

As activity progressed into small to moderate eruptions at Stage 3 (VAL 3-4), concern was reported as high because of uncertainty about what the volcano might do next, but there was also concern for emerging impacts, and the roles that participants had to play in dealing with those impacts. This concern meant that information needs were high, with many suggesting they would be proactively seeking information during this stage, as mentioned by a participant from TPM1 who said, *“Well I’d be checking more often. I’d be checking probably about every hour now.”* Reworking and redistribution of information would also take place. Agencies recognised the demand that would be placed on them during an eruptive sequence, as highlighted by a New Plymouth participant:

“... ‘cos [...] the communication systems going to [...] be really tested, people ringing in and all that stuff. People will be going what do I do?” (TK4).

Participants wanted to have access to information regarding the volcano’s status, changes in monitoring data, forecasts and areas impacted. However, at Stage 3 there was also a strong focus on needing to understand the nature of hazards produced (including but not limited to ash) and a need for information on sector-specific impacts and mitigation (e.g., for people, animals, buildings, infrastructure, equipment), tailored to different contexts. It was anticipated that this should be coupled with rapid, clear information about specific actions to take to help guide response activities. Participants noted that provision of targeted and specific information, might help reduce the information overload issues noted as an issue in the first two stages:

“It’s interesting, because you want clear, don't you. You don't want information overload. It’s like what's going to affect those people? How do you get that information quickly to them? So, if we’re in Taupō and the cloud’s coming directly for us [from Ruapehu], on Facebook, if we got ash is coming our way, this is what to do.” (TAM2).

3.5.2.4 Scenario Stage 4: Post- eruption/Eruptions stopped (VAL 2)

At Stage 4, when eruptions stopped, concern tended to reduce because of the de-escalation of activity, and participants perceiving the imminent danger had passed. However, uncertainty about whether eruptions might potentially reactivate, ongoing impacts and participant

responsibilities, also meant that some concern was still relevant during this stage which might last for some time.

“I’d be worried about a re-escalation, and like you say, the PIM [Public Information Management] staff would, like people, still want to know no matter what’s in their heads, they want to know, continuously. So re-escalation, and also like as we know, when something’s happened it takes a long time for us to get back to BAU.” (HB1).

“It would have to have stopped for six months for me to actually start to feel, you know...” (TPM1).

Consequently, a wide range of information was still deemed relevant post-eruption, including needing to know the volcano’s status, forecasts, areas impacted, nature of the hazards and sector specific impacts. In this stage there was a focus by participants on understanding the long-term nature of impacts, and the mitigation measures and response actions required to alleviate these impacts. Regarding information overload, some participants felt that this could be addressed at Stage 4 by directing people to known sources (that they may already have been exposed to throughout the sequence) where they could get updates without being bombarded by constant information.

“After, what are we through this episode, almost five months through it now, there might almost be overload, you know, you might be getting a wee bit kind of worn down by having too many updates again, and, for me, it’s probably knowing where to find more information just like [for] those areas. Personally, I’d probably go looking.” (TPM3).

“Well the frequency could be on the website rather than in the media [...] ‘We will update weekly at info-dot-info-dot- info’” (TPM3)

Table 6. Drivers of concern, perceived information needs and anticipated actions for stages 1-4 of the Ruapehu scenario. Bolded/italicized text represents items raised by participants that are unique to a stage, or differ from a previous stage, highlighting how needs might evolve over time.

Stage 1: Quiescence/BAU (VAL1)		
Drivers of concern	Information needs	Actions
Lower levels of concern: nothing happening/normal, volcano far away, is monitored and will receive warning, aware but unconcerned, previous knowledge or experience. Elevated levels of concern: uncertainty – activity can occur anytime (might evolve quickly), roles and responsibilities, provision of information might spark concern.	Information seeking – ‘active monitoring’; or prompted by a notification or activity (tramping, planning) Continual updates on a volcano not a priority; interested in changes Reduce information overload Want to know where to get more information Background information - for education, preparedness and planning Precursors to an eruption How might volcanic activity affect me/us? (helps understand impacts, safety, and to prepare/plan) A need for balance – to avoid anxiety Information less desired or contested: danger, scientific details about what’s causing activity, what’s happened in past. What we need to do now.	Publics: ‘Active monitoring’ & additional information seeking Preparedness and planning. Agencies: ‘Active monitoring’ & additional information seeking Maintain awareness Provision/communication of information Preparedness and planning Build relationships.
Stage 2: Moderate to heightened unrest (VAL 2)		
Drivers of concern	Information needs	Actions
Lower levels of concern: nothing much directly affecting people so far, volcano far away, aware but unconcerned, previous knowledge or experience. Elevated levels of concern: change in activity and VAL; uncertainty over what volcano will do; past experience of Ruapehu/other volcanoes (e.g. Whakaari); roles and responsibilities; provision of	Proactive information seeking from wider range of sources, used for intel, confirmation and reassurance What is the volcano doing now - more frequent updates Basic scientific details about what’s causing activity Changes over time (e.g. using basic monitoring data) What will the volcano do next? (including forecasts) Precursors to an eruption Unfolding indirect impacts, and potential impacts Areas potentially affected Will this affect activity at other volcanoes? Reduce information overload (over-alerting, too much info for public) A need for balance – to avoid anxiety	Publics: Proactive information seeking Information reworking and/or redistribution Change plans (e.g. not go to Ruapehu) Preparedness and planning. Agencies: Proactive information seeking Maintain awareness (“monitoring mode”) Information reworking and/or redistribution Provision/communication of information Preparedness & planning (if not done already) Access/activate plans & stand-up agencies Support agencies, or bring in support

information might spark concern.	Information contested: danger, certain impacts (e.g. economy), what's happened in past What we need to do now.	Ensure relationships in place Mitigate indirect impacts.
Stage 3: Small to moderate eruptions (VALs 3-4)		
Drivers of concern	Information needs	Actions
<u>Lower levels of concern:</u> Uncertainty of an eruption has reduced (it has happened); similar to previous events; size of eruption is small/moderate. <u>Elevated levels of concern:</u> uncertainty over what volcano will do, or uncertainties over impacts; being located closer to volcano; roles and responsibilities; seeing or experiencing impacts yourself or having someone close to you experience impacts.	Proactive information seeking from wide range of sources What the volcano is doing now Changes over time (e.g. using basic monitoring data) What will the volcano do next? (including forecasts) <i>Nature of hazards, e.g. particularly ash</i> Areas affected <i>Sector specific information on impacts e.g., people, animals, buildings, infrastructure, equipment, etc., and mitigation measures</i> <i>Historic info - what happened before, what might happen now</i> <i>Hazard processes - whether a location might be impacted and how</i> Whether this will affect activity at other volcanoes Reduce information overload – provide <i>quick clear information about what to do</i>, especially for the publics. <i>Information that connects emotionally.</i> <i>Information not needed: what's causing the activity; precursors</i> What we need to do now – especially specific actions to take.	<u>Public:</u> Proactive info seeking; however, some will wait Information reworking and/or redistribution Change plans (e.g. work, recreation) Preparedness & planning (e.g. evacuation planning) Response actions (including mitigating impacts). <u>Agencies:</u> Proactive information seeking Information reworking and/or redistribution Provision/communication of information (esp. specific messages for sectors, or communities) Preparedness & planning (if not already done) Response activities (e.g. evacuation, mobilizing staff, resourcing, welfare, mitigating impacts, insurance) Support agencies, or bring in support.
Stage 4: Eruptions have stopped / Post eruption (VAL2)		
Drivers of concern	Information needs	Actions
<u>Lower levels of concern:</u> Eruption has happened; activity has de-escalated; VAL reduced; imminent danger has passed. <u>Elevated levels of concern:</u> uncertainty over reactivation of eruptions (take up to 6 months for this uncertainty to drop); ongoing impacts; roles and responsibilities.	Proactive information seeking - guide response/recovery decisions What the volcano is doing now What the volcano will do next (including forecasts) Nature of hazards, e.g. ash, in the long-term context <i>Targeted information, e.g. weather info to understand ash reworking</i> <i>Areas affected – e.g. maps of deposits, secondary hazards</i> <i>Sector specific information on long term impacts - people, animals, buildings, infrastructure, equipment, etc., and mitigation measures</i> Historic information - what happened before, what might happen now <i>Precursors – in case there is another eruption</i>	<u>Publics:</u> Proactive information seeking Changing plans (e.g. not painting a roof until later) Ongoing response and recovery actions (including mitigating longer-term impacts) Longer term recovery planning and decision-making <u>Agencies:</u> Proactive information seeking Information reworking and/or redistribution Provision/communication of information (especially specific messages for sectors, or communities)

	<i>Reduce information overload – by S4 might know <u>where</u> to get information, without being overloaded</i> (e.g. a background website). Information not needed: what's causing the activity; whether this will affect activity at other volcanoes What we need to do now – especially specific actions to take.	Response activities (e.g. resources, welfare, mitigating impacts, debris management, insurance) Supporting agencies, or bringing in support Multi-agency discussions re: post-eruption actions Waiting to resume some activities.
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3.5.3 An updated diagram for critical information needs at each scenario stage

Drawing upon the card sorting exercise, which highlighted critical information needs based on topics provided by the researchers (Figure 9), and a more detailed analysis of the focus group discussion data, a revised conceptual diagram of critical information needs was developed (Figure 10). Figure 10 aligns well with Figure 9, however discussion data highlighted that some information is critical across more stages than indicated by the card sorting exercise itself (i.e. information about precursors, what the volcano has done in the past, what the volcano will do in future, impacted areas, and what needs to be done now). Discussions also highlighted the need to introduce a new topic to the diagram regarding the importance of relationship-building in Stages 1 and 2. Representation of information needs across different stages can build upon existing basic communication frameworks (e.g., Fearnley et al., 2018) to allow a more nuanced understanding of requirements across time, and better targeted information provision.

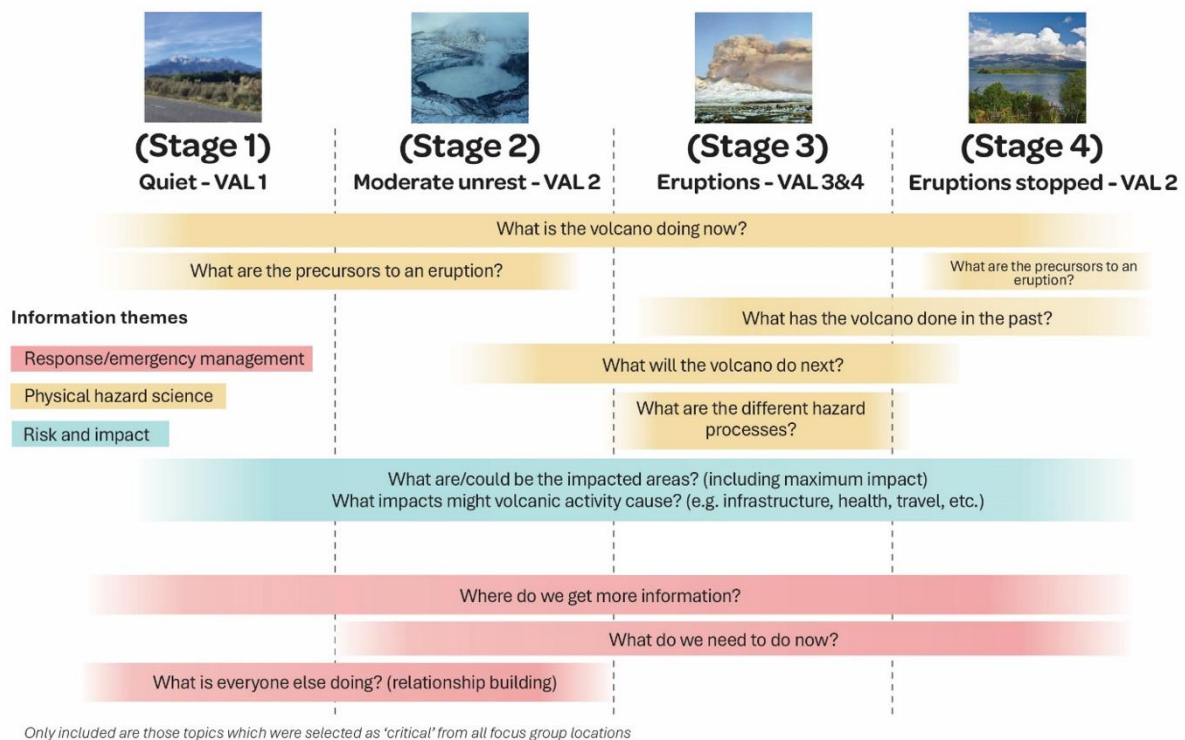


Figure 10. Critical information needs at each stage of volcanic activity, drawing upon the card sorting exercise, (Figure 9), and a detailed analysis of focus group discussion data.

4.0 Discussion and recommendations

Given the results from the research, what recommendations do we have for volcano observatories, national monitoring agencies and other sector-based information providers in developing and delivering volcano information?

Recommendation 1. Ensure relevance to context

It is important to account for the context in which volcanic information is required (e.g. our participants discussed contextual aspects related to location, prior experiences, indigenous perspectives, volcanic activity, and more). Prior research highlights that information should be salient to people's contextual needs (Ronan et al., 2000) to ensure it is of relevance. Given the importance of context, a diversity of fit-for-purpose information could be developed and personalised across different stages of volcanic activity to ensure relevance to various publics and agencies' situations (Andreastuti et al., 2023; Becker et al., 2019; Gabrielsen et al., 2017; Mileti et al., 2004; Rouquette et al., 2023).

Recommendation 2. Consider source, channel, and content for specific audiences

Our research highlighted differences in how information is sourced by publics versus agencies, with publics accessing half the number of sources or channels that agencies did. While there was some alignment between the two regarding use of sources like GeoNet or emergency management organisations, agencies also used a wider range of sources and channels to seek sectoral information (e.g., infrastructure, lifeline agencies, etc.). We recommend targeting information to the sources and channels that each is most likely to access.

However, we caution about too simplified an approach; publics and agencies are not homogenous entities in themselves and within those groupings will require access to a diversity of sources and channels, as well as diversity in content, depending on the context within which they are operating as noted above (Becker et al., 2019; Ronan et al., 2000). Therefore, it is useful to undertake further research to understand specific user needs to develop more targeted information provision.

A challenge with having a multitude of different types of information available from different sources and channels, is the potential for misalignment of messages. Participants thus also highlighted the necessity to ensure consistency across multiple sources and channels, and this should be factored into information development and dissemination efforts (Mileti et al., 2004; Newhall & Solidum, 2018; Perry & Lindell, 2018; Ronan et al., 2000; Todesco et al., 2022).

There was discussion within the focus groups about the importance of having credible and trusted sources and channels (Andreastuti et al., 2023; Fearnley and Beavan, 2018; Graham et

al., 2022; Haynes et al., 2008; Newhall & Solidum, 2018). Perceived or actual trust in information sources has long been identified as essential for prompting individual and collaborative action (Bird et al., 2011; Kirschenbaum et al., 2017; Owen et al., 2013; Paton 2008; Siegrist & Cvetkovich 2000). Trust in sources such as civic agencies is important, as in turn, this affects trust in the information provided (Paton et al., 2008; Sagala et al., 2009); and if people do not trust information, they may not act to reduce their risk. Therefore, the development of trusted relationships between sources and recipients is also essential.

Recommendation 3. Develop a planned approach to information provision to anticipate public concern and interest levels.

The results from our research highlighted, unsurprisingly, that people's concern grew as activity from the Ruapehu scenario increased, elevating the perceived importance of information, which peaked during Stage 3 of eruptions. The need for critical information also grew throughout the stages, as people anticipated requiring more specific and detailed material (Lowenstern et al., 2022), and was at its most complex by Stage 4.

Past volcanic events have shown that demand for information escalates as activity increases (Becker et al., 2017; Stewart et al., 2017; Mani et al., 2025; Todesco et al., 2022), but this research also confirms that participants anticipate significant information demand during future events, highlighting the need for a planned approach for provision of that information by science and responding agencies. Additionally, because the context changes as volcano activity evolves, information should evolve over time to account for such changes (Andreastuti et al., 2023; Doyle & Becker, 2022; Rouquette et al., 2023). A planned approach to information provision across different stages of activity is advised, to ensure the communication of timely (Mulliken et al., 2026; Todesco et al., 2022), regular, and sustained information, as called for by participants.

Recommendation 4. Prepare plain language information (or templates to populate) on *physical hazard science* ahead of volcanic activity.

Considering critical information needs, both publics and agencies highlighted a range of physical hazard science that was important to know. These included what the volcano is doing now (Stages 1-4), what the precursors to an eruption are (Stages 1,2,4), what a volcano has done in the past (Stages 2-4), what a volcano might do next (Stages 2-4), and an understanding of hazard processes (Stage 3). It was felt that any information provided should not be too technical, as articulated in Table 3. Information provided should be simplified and clear enough for end-users to understand, make sense of, and use in their decision-making (McGuire et al., 2009; Mileti et al., 2004; Hufstetler et al., 2026).

In considering the focus for this simplified information, participants mentioned a range of types or formats of information that they considered useful for articulating volcano science

across different stages. These included background information about volcanoes (e.g. types, style, eruptive histories); VALs; VABs; monitoring data (showing changes over time); likelihoods/probabilities, forecasts, scenarios, visual information (e.g. infographics, videos, live webcams), hazard maps (e.g. ash forecasts or deposits, potential or real lahar extents), and weather information. While many of these are available in New Zealand already, other types of information certainly exist beyond those discussed (e.g. see Lowenstern et al., 2022), and could be aligned and developed considering the critical needs for different stages listed above. Some information could be prepared in advance of escalating activity, or templates provided to populate when activity changes. It is also important to remember to evaluate such information, to ensure it meet needs and is updated accordingly, and this should be factored in to the overall process (Doyle and Becker, 2022).

Recommendation 5. Provision of *risk information* to publics and agencies should be determined, planned and templated ahead of time.

In addition to physical hazard science, participants highlighted the criticality of risk and impact information across all stages (1-4), including needing to know which areas could be impacted and the impacts volcanic activity might cause. The type of information required depended on the context at each stage. For example, at Stage 1 the potential risk, impacts and extent were required to assist in planning for a future volcano eruption (e.g. via scenarios, and hazard and risk maps), whereas at Stage 3 there was more pressure for real-time information about on-going and future risk and impacts to assist with response (e.g. ash forecasts, ash deposit maps, ash impacts on infrastructure, health, or society), as highlighted in real events in New Zealand and internationally (e.g. lava flows - Mulliken et al., 2026; Pedersen et al. 2023).

Consequently, the focus group data highlighted that the need for information about risk and impacts is important across every stage and should be provided full attention (Blong 1996; Deligne et al., 2017; Weir et al., 2024). This is in contrast with the critical demand for physical volcano science information which varies over time depending on activity (See section 3.5.1). The former is especially important for agencies, who were more likely to indicate than publics, that is critical to have risk and impact information in stages 1-2. Given we know risk and impact is important, continued planning for the provision of such information before, during and after activity should take place.

Recommendation 6. Develop information to *support action*.

Information is critical in supporting the actions publics and agencies need to take in response to volcanic activity. Information can help inform preparedness and planning for a volcanic eruption at Stage 1 and 2. From Stages 2-4, information to support emergency management activities such as evacuation, deployment, or infrastructure protection emerge as priorities,

alongside protecting people from hazards such as ash, and providing advice on clean-up or insurance. Participants called for directive information that helps prompt actions in line with other studies that highlight the value of providing direct advice (McGuire et al., 2009; Mileti et al., 2004; Hufstetler et al., 2026).

Participants provided suggestions on the types of information they'd like to see to support effective action – including directive information about actions to take (e.g., store water and food beforehand; wear a mask during ash-fall), targeted messaging (similar to “Drop, Cover, Hold” for earthquakes), and the broad use of products to aid effective responses (e.g., maps showing exclusion areas, or “safe” areas; signage). Some of these already exist (e.g. Leonard et al., 2008; 2014) but further thought and development would be useful.

While not explicitly covered in this study it is important to note other factors can also influence taking action. Personal attributes such as self-efficacy and/or response efficacy (i.e. the belief that an individual is capable of undertaking preparedness actions or responding appropriately) and outcome expectancy (the belief that preparing or planning will help reduce volcanic risk or impacts) (Perry & Lindell, 2008; Vinnell et al., 2021; Wei & Lindell, 2017) influence actions, as do community attributes like collective efficacy (the belief that a community or group is capable of acting together), social capital, community participation and empowerment (Paton et al., 2008; Sagala et al., 2009). Information should be framed or delivered in such a way to support such attributes, and ensure actions are taken (Paton et al., 2024). As an example, in our study, TAM2 identified how information can provide a sense of control and empowerment to enable people to make decisions and take actions (see Section 3.3). Thus, such aspects should also be considered when developing and communicating information, particularly with publics.

Recommendation 7. Design information to avoid overload (i.e. concise and layered content).

Publics expressed a desire not to be overloaded with information at stages when a volcano was either quiet (quiescence stage) or in minor-moderate unrest, often due to concern or anxiety. Some agency-based participants also identified information overload as a potential issue during these stages. Throughout all stages, however, people desired to be able to find more information if needed, aligning with Mileti et al's (2004) recommendation to support people to seek information. People seek information to help to make sense of issues, confirm existing information, help with decision-making, and alleviate negative emotions (Becker et al., 2012; Ryan, 2018).

To reduce overload but still ensure enough information is available for those who seek it, volcano observatories, national monitoring agencies and other information providers could develop information in ways that provide essential concise content, supported by access to additional information as part of a layered approach (Wood et al., 2017). In a New Zealand

context, opportunities might include online links on the GeoNet website; or links on the National Emergency Management Agency volcano pages (NEMA, 2026). This approach has also been identified as useful for other perils like earthquakes where basic information is important as a first step, but with users able to access more detailed information (Becker et al., 2019; 2020).

Recommendation 8. Plan for the reworking and redistribution of complex information for lay-audiences.

As volcanic activity increases and pressure for information grows, agencies acknowledge that they will need to rework volcano information for downstream dissemination (Nurjanah et al., 2026). This is likely to require re-framing complex physical hazard science and risk and impact information in the context of lay audiences, in ways that can be useful to responders. In anticipation of this need, science agencies could develop fit-for-purpose information which can be easily redistributed to lay audiences, and response agencies could also give thought beforehand about the kinds of reworked information they might need to provide.

Partnerships between science agencies and other organisations (including indigenous groups) are also important in ensuring the success of intermediaries effectively reworking and passing on important information (Mileti et al., 2004; Nurjanah et al., 2026; Garcia & Mendez-Fajury, 2018; Mulliken et al., 2026; Ronan et al., 2000). One New Zealand example of pre-developed material is the *Consistent Messages for CDEM* document (National Emergency Management Agency, 2006), which contains nationally agreed consistent messages for use by emergency management agencies, including a section on key messages for use during volcanic activity. Another example relates to volcanic ash resources developed in advance of an eruption to assist end users (Wilson et al., 2014; Volcanic Ashfall Impacts Working Group, 2023).

Recommendation 9. Continue relationship building activities between agencies and communities.

In line with the concept of collective efficacy (Sagala et al., 2009), the data also highlighted the value of relationship building (McGuire et al., 2009; Mulliken et al., 2026) at stages 1-2 amongst agencies, in helping prepare for and respond to a volcanic event. Thought could be given on how to best support this activity. For example, the use of Volcano Advisory Groups (e.g. CPVAG, TVSAG), where interagency meeting and planning regularly occurs, have been one mechanism to build these relationships, which has notably improved inter-agency responses when volcanic events have occurred (Becker et al., 2017; Doyle and Johnston, 2011; Doyle et al., 2015; Doyle & Paton, 2017; Lowenstern et al., 2022). The benefit of such groups is not related to information per se, but they provide a mechanism for information sharing and planning, which assists in developing a shared mental model of how they will

respond to a future event (Doyle et al., 2015; Doyle & Paton 2017). Agency participants explicitly suggested they valued this aspect, and relationship building should continue to be supported.

4.1 Future considerations

While this paper does not explore in-depth publics or agency knowledge about volcanoes, the data did highlight some work to do to grow understanding. For example, as shown in Table 5, the question, "Will this affect other volcanoes?" came up several times, and it also emerged as a critical information need during the card sorting exercise for Stage 3 – eruption. Therefore, it was evident from our work that there is still confusion about whether activity at one volcano might affect another. Similarly, we saw misunderstandings about the extent of impacts that an eruption from Ruapehu volcano might bring to some communities (i.e. public participants in Rotorua overestimated the potential impacts for their location), and knowledge gaps around caldera volcanoes. Even where people feel confident in their knowledge, misunderstandings about volcanoes have been noted by other researchers (Haynes et al., 2008; Solana et al., 2008), highlighting an ongoing challenge with respect to up-skilling people about volcanoes. Consequently, there are still opportunities before an event to grow the knowledge and capacities of publics and agencies, which this research can help guide.

A challenge we face going forward is how the development and provision of information will operate in a world where Artificial Intelligence (AI) is growing in use. Already in AI-assisted social media we see audiences' hunger for rapid information, and issues related to the rise of mis- and dis-information (Todesco et al., 2022). Further problems relate to the quality of data and information provided, loss of control and diminishing trust in information (Ogie et al., 2018). The value of this study is that it reports on the critical pieces of information needed by publics and agencies during different stages of volcanic activity. Those needs remain; however, how we choose to fill them will need to be addressed. Future work should reflect on how AI can contribute meaningfully, so that people can continue to have access to information that reflects good practice, and allows them to make effective decisions before, during and after volcano crises.

4.2 Study limitations

Our study includes several limitations. In the first instance, one scenario of an active volcano in New Zealand cannot cover the whole range of possible events that could happen in a future volcanic episode, and therefore our results should be interpreted within the context of the scenario used. Additionally, our participants were more likely to have more interest or experience with volcanoes and this may introduce some bias to the results; those with less experience might have differing levels of concern or perspectives on information needs. Our data is also based on a small quantitative sample of responses to Questions 1 to 3, combined

with qualitative analyses of discussions. Therefore, while the study provides excellent detail regarding the scenario we used, there would be benefit in conducting a larger quantitative survey or undertaking further scenario-based case studies to see if our results are more broadly applicable across other volcanic settings and population groups.

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Clinical trial number: not applicable

Human Ethics and Consent to Participate declarations: This study was conducted following Massey University's Human Ethics Procedures and constituted a Low-Risk Notification (Number: 4000026243).

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