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'Sharing is caring': A socio-technical analysis of the sharing and governing of hydrometeorological hazard, impact, vulnerability, and exposure data in Aotearoa New Zealand

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ABSTRACT

There has been a growing recognition of the need to collect disaster and risk data over the last two decades. Accordingly, better collection and management of disaster data was identified as a priority of the Sendai Framework for Disaster Risk Reduction. The introduction and implementation of Impact Forecasts and Warnings (IFWs) have further highlighted this need to collect and access hazard, impact, vulnerability, and exposure (HIVE) data. However, challenges have been met with reporting and using disaster data, which have resulted in an identified need to establish principles for data collection, recording, reporting, exchange/sharing, and comparability. This introduces the concept of data governance and management for disaster data, particularly with regards to data custodianship, stewardship, and sharing.

Using Grounded Theory, a series of interviews were conducted with users and creators of HIVE data to develop further understanding around managing and accessing it for severe weather hazards in New Zealand. A socio-technical lens guided the analysis to identify the organisational and technical intervening conditions and action/interaction strategies for accessing and sharing HIVE data in NZ.

Findings indicated that there is a need to establish data governance principles for HIVE data in New Zealand. An additional need was identified for nurturing partnerships to continue building trust between stakeholders for sharing data. Furthermore, integration challenges continue to interfere with the use of various sources of HIVE data for effective risk and impact assessments for IFWs and beyond. Systematic and standardised data collection approaches using GIS-based tools can support integration.

1. Introduction

There has been a growing need to collect disaster and risk data over the last two decades (e.g., [32]). Accordingly, better collection and management of disaster data was identified as a priority of the Sendai Framework for Disaster Risk Reduction [81]. In response, global initiatives now exist with the objective of developing technical guidance for building up disaster and risk data, such as the Integrated Research on Disaster Risk (IRDR) programme and subsequent workshops [12,25]. The introduction and implementation of Impact Forecasts and Warnings (IFWs) for hydrometeorological hazards (e.g., [84,88]) has further highlighted the need to collect and access relevant disaster data for mitigation and prevention; namely hazard, impact, vulnerability, and exposure (HIVE) data [35,70]. However, challenges have been met with reporting and using disaster data, such as the fact that many stakeholders are involved in the collection, creation, and use of disaster data, making it difficult to integrate different data sources and perform comparative analyses [18]. These challenges have resulted in an identified need to establish principles and standards for data collection, recording, reporting, exchange/sharing, and comparability [25]. This

Abbreviations: IFW, Impact Forecast and Warning; HIVE, Hazard, Impact, Vulnerability, and Exposure; DRR, Disaster Risk Reduction; IRDR, Integrated Research on Disaster Risk; EWS, Early Warning System; NHP, Natural Hazards Partnership; LINZ, Land Information New Zealand; NZTA, New Zealand Transport Agency; NMS, National Meteorological Service; ES-GT, Evolved-Straussian Grounded Theory; CDEM, Civil Defence and Emergency Management; EM, Emergency Management; NEMA, National Emergency Management Agency; GNS Science, Institute of Geological and Nuclear Sciences Limited; NIWA, National Institute of Water and Atmospheric Research Limited; NZGIS4EM, New Zealand Geographic Information Systems for Emergency Management; GIS, Geographic Information Systems; COP, Common Operating Picture; CAP, Common Alerting Protocol; FENZ, Fire and Emergency New Zealand; IDSS, Impact-based Decision Support System.

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introduces the concept of data governance for disaster data [12,45,56], particularly with regards to data custodianship, stewardship, and sharing [69,86].

Building on recent research where we identified the data needs, uses, and sources of HIVE data for implementing hydrometeorological IFW systems in Aotearoa-New Zealand (see [34,35]), we aim to develop further understanding around managing and accessing these data sources. We begin by presenting background on data governance and management, and data access and sharing, where data accessibility can affect data sharing [64].

1.1. Data governance

Data governance is an emerging field of research, with no agreed-upon definition [1]. We adopt the definition provided by Benfeldt et al. [7] where "data governance refers to the organisation and implementation of rules and responsibilities, which enforce decision making and accountabilities regarding an organisation's data assets" (p. 299). This is different from data management, which focuses on defining the data element, and how it is stored, structured, and moved [1]. Thus, data governance is argued to be a higher level of "planning and control over data management" ([1], p. 841).

There has been little mention of governance for disaster loss data in the disaster risk reduction (DRR) literature, except when it is pointed to as a need to improve data quality, access, sharing, and interoperability (e.g., [12,45,56]). Clarke et al. [12] proposed that data governance and independence be established for "strengthening and protecting data quality through national statistical offices that are functionally autonomous from other government agencies" (p. 4). Migliorini et al. [56] identified a lack of appropriate data governance arrangements to be impeding data access for DRR. Similarly, Li et al. [45] identified issues around data governance when using population health data for disaster risk research. In Aotearoa-New Zealand, Crawford et al. [14] identified challenges with risk data collection due to unclear roles and responsibilities for doing so. Beyond these examples, we could not find studies that specifically investigated disaster data governance, despite the apparent need to establish appropriate data governance measures for improved data quality, sharing, and integration.

One element of data governance involves assigning roles and responsibilities, including decision rights and accountabilities, around how the data is managed, secured, validated, and made available [1,2,7]. Two such roles are data stewardship and data custodianship [86]. Often these roles may be confused or merged, however, they have distinct roles and responsibilities, discussed next.

1.1.1. Data stewardship and custodianship

Data stewardship and data custodianship relate to roles for managing data. In the context of health data, data stewardship consists of developing methods for "acquisition, storage, aggregation, deidentification, and procedures for data release and use" ([72], p. 1444). Similarly, the New Zealand (NZ) Government defines a data steward as an agency that operates at the systems and strategic level and promotes good practice to manage the data over its lifecycle, including planning and adjusting for technological obsolescence and long-term preservation and access [50,73]. Related, but distinct roles, are data custodians. For NZ government data these custodians are agencies that implement the data management practices stipulated by data stewards in daily practice [73] to ensure the quality and accessibility of the data [50].

In Aotearoa-New Zealand, several agencies have a data stewardship and/or custodianship role. Toitū Te Whenua Land Information New Zealand (LINZ; the government agency responsible for managing land titles, geodetic and cadastral survey systems, topographic information, hydrographic information, etc.) provided a *Steward and Custodian Framework for New Zealand Fundamental Geospatial Themes and Datasets*, to outline the responsibilities and expectations of appointed custodians and stewards of fundamental geospatial data (see [50]). LINZ also provided a partner document outlining the process of identifying and selecting fundamental geospatial data (see [49]). In summary, datasets are proposed to the New Zealand Geospatial Office for evaluation against a set of criteria to classify it as a fundamental geospatial dataset [49]. Fundamental geospatial datasets are "datasets that provide the minimum core set of nationally-significant data that are critical to the effective running of [Aotearoa-New Zealand], and work together to help support growth in the economy" ([49], p. 4). Most of these fundamental geospatial datasets are not considered disaster datasets as they do not convey disaster losses, impacts, or risks. However, much of these underlying datasets can inform vulnerability and risk assessments when used in risk models and overlaid with hazard data to determine exposure (see [34,35]).

The fundamental geospatial datasets identified by LINZ are labelled as either Suggested (i.e., the agency suggested by LINZ has not yet agreed to the role and may not have been approached yet), Proposed (i.e., the suggested agency has agreed to the role but the commitment has not yet been formalised), Appointed (i.e., the proposed agency has formally committed to the role), or Not Evaluated (i.e., the datasets were proposed as fundamental datasets but were not yet evaluated to determine their status) [49]. For example, the Waka Kotahi New Zealand Transport Agency (NZTA) is the proposed custodian for the leadership and delivery of the national road network, while local government and territorial authorities are the suggested respective leadership and delivery custodians for council roads. Leadership Custodians ensure that appropriate data management policies and standards are developed while Delivery Custodians are "responsible for the continued physical existence, availability, and integrity of the dataset" for as long as is required by the leadership custodian ([50], p. 25).

Like disaster data governance, there is little mention of the stewardship of disaster data in the literature. This gap has been identified by Fakhruddin et al. [24] who identified the need for building capacity in data collection and stewardship to support reporting to the Sendai Framework, an international accord outlining global priorities for disaster risk reduction (DRR) [81]. Another challenge faced in DRR is accessing and sharing the required data [23] for emergency/disaster response, risk analysis (e.g., risk modelling and risk assessments), vulnerability assessments, and supporting IFWs [14,34,35].

1.2. Data access and sharing

Many stakeholders are involved in DRR who collect, produce, and manage their datasets. Access to and sharing of these datasets is necessary for DRR [24]. For example, in places like Europe with many countries sharing borders, it is important to be able to share data across borders [16]. Within a country, sharing data is important since, in many cases, disaster and risk data are collected by different agencies [34,35]. Data access refers to the retrieval and storage of data provided by the data holder and may be subject to technical, legal, and/or organisation requirements [64]. Data sharing is the voluntary provision of data by the data holder, including commercial and non-commercial conditional data sharing agreements [64]. Data accessibility is a spectrum, ranging from closed data to open data, and affects data shareability [64]. Data sharing is a socio-technical activity as it involves various parties forming data-sharing partnerships and technical systems to support integrating multiple datasets.

1.2.1. Organisational aspects of data access and sharing

Sharing disaster and risk data requires building partnerships between data stakeholders [23]. The Natural Hazards Partnership (NHP) is an example of a formal partnership developed in the UK between public agencies to improve disaster management across the country, including sharing data between the various agencies [36]. Building the NHP required extensive time, coordination, communication, and interaction between agencies [36].

Multi-organisational collaboration is wrought with challenges [74]. Building trust and increasing the willingness of organisations to participate is the first hurdle to overcome [74]. After this, new challenges include mutually identifying goals and objectives and agreeing on timelines, uses of differing terminology and epistemologies, legal issues around intellectual

property, and developing workflows and communication standards [74]. These early stages of scouting and building trust can take years [74]. Sustaining collaboration (e.g., maintaining interest and securing funding sources) remains an ongoing challenge [36,74]. In addition to building partnerships to share data, technical solutions are needed to enable data integration.

1.2.2. Technical aspects of data access and sharing

Data integration and interoperability are important, yet challenging, technical factors that support data sharing for DRR [23]. Disaster and risk data are available in countless formats, making integration difficult [39]. Thus there is a need to understand the various data sources and how they can be effectively and efficiently used [39].

Interoperability is a familiar challenge for both Early Warning Systems (EWSs) and data sharing and integration [10,38]. Interoperability issues for EWSs emerged as technological advancements led to a plethora of warning delivery mechanisms [10]. The Common Alerting Protocol (CAP) was proposed to set standards for warning design and delivery [10]. The CAP relies on standardising warning data for sharing across platforms [63,71]. The introduction of IFWs further adds to the challenge of standardised data exchanges [41,70].

In Aotearoa-New Zealand the Canterbury earthquakes from 2010 to 2011 laid bare gaps in interoperability for data sharing during and after the disaster, and the need for standards-based interoperability for improved information and data management [79]. Furthermore, the NZ Civil Defence and Emergency Management (CDEM) sector is striving towards a Common Operating Picture (COP) in which all agencies and stakeholders involved in an event can access and view the same information [17]. This involves developing standards and capabilities for enabling access to and sharing of datasets [79].

Harrison et al. [34,35] identified and reported the various sources for HIVE data for hydrometeorological hazards in Aotearoa-New Zealand. While the data sources were identified, more understanding is needed around managing and accessing these data both for IFW systems and for general DRR [34,35].

The objectives of this research are to identify and understand the governance and acquisition process for hazard, impact, vulnerability, and exposure (HIVE) data for hydrometeorological hazards in Aotearoa-New Zealand, to support efforts to fulfil the Sendai Framework priorities around disaster data access and to support the implementation of a hydrometeorological IFW system.

2. Research methods

We used a qualitative approach to address the research question, specifically employing the Evolved-Straussian Grounded Theory (ES-GT) research strategy for data collection and analysis [13]. Interviews, workshops, and key documents were the primary data sources. Between November 2018 and April 2021, the lead author interviewed thirty-nine ($n = 39$) experts in weather forecasting, warning, emergency management, risk modelling, and data collection and management (see [35] for more information on the participant details). Three virtual workshops were held in Aotearoa-New Zealand. Two of these workshops involved Emergency Management (EM) practitioners, weather forecasters, communication and data specialists, and hydrologists from the Auckland ($n = 4$) and Southland ($n = 5$) Regions. The third workshop involved a portion of the NZ risk and hazard science community based at GNS Science ($n = 11$). Thus, 59 people participated in this research.

Interview questions and workshop activities focused on themes regarding IFW data needs and sources. We asked for participants' general thoughts on IFWs; what impact, vulnerability, and/or exposure data they use or need, why, and how; the life path of the data; experienced and/or perceived challenges obtaining data required for IFWs and other uses; and thoughts on collecting and using alternative data sources (e.g., social media and crowdsourcing). Findings around data governance and acquisition are reported in this paper.

This research was collected under a 'low risk' ethics notification with the Massey University Human Ethics Committee. All interviewees remain anonymous and are assigned an alphabetic code (A, B, C, etc.), being identified only by the area of expertise and/or practice, industry, location, or governance level (Table 1). Interviews were audio-recorded and transcribed verbatim, and qualitative analysis (including coding and memo-writing) followed the axial coding paradigm according to the ES-GTM [13], using NVivo 12 qualitative analysis software [8].

Per ES-GT, analysis of the interviews, workshops, and documents followed the open coding (assigning concepts and categories to an instance of the data by line or by word), axial coding (relating categories to each other with optional guidance from the coding paradigm), and selective coding (relating all categories to a core category) stages [77]. The coding paradigm introduced by Strauss and Corbin [77] supported the axial coding stage whereby the codes created from the open coding stage were related to the coding paradigm dimensions (Table 2) for increased density and precision.

Additional techniques were used to support the ES-GT analysis, including regular memo-writing, diagramming, and constant comparison [29]. When the lead author noticed common themes in the interview and workshop data, a memo was written to identify the theme and discuss its relation to other concepts or themes (i.e. constant comparison) [13,29]. Diagramming was used to draw out linkages or relationships between the emerging themes. This was an iterative process that occurred during the data collection and analysis.

From the axial coding process (summarised in Table 2), two phenomena related to data management and acquisition of hazard, impact, vulnerability, and exposure data were identified. Phenomena are the subjects or objects under study [77]. Impact forecasts and warnings and HIVE data were identified as the overarching phenomena being studied in this research. As data collection and analysis progressed, the two phenomena that became the focal point of this manuscript were identified from the themes that emerged in the interviews, memo-writing, diagramming, and constant comparison techniques previously described. These two phenomena are: (1) The Roles and Responsibilities of Data Custodianship, and (2) Data Access and Sharing. These are discussed next.

3. Findings and discussion

The two phenomena (The Roles and Responsibilities of Data Custodianship and Data Access and Sharing) were succinctly summarised by an NZ-based risk modeller, who said:

> I think it really comes down to … sharing and collaboration … and I think there are good efforts, but … often things get snagged in … a privacy or confidentiality or legal issues with the datasets, who owns them, who maintains them, how can you rely on them … And the amount of work that is required to produce and maintain a reliable dataset is massive, it's just so much work that people don't want to do it. It costs money, it costs time, and … being a custodian of a dataset is not really an enviable position, necessarily. I think that's probably one of the biggest barriers (Risk Modelling NZ. A).

These two phenomena (the roles and responsibilities of data custodianship, and data access and sharing) will each be discussed in turn.

3.1. The roles and responsibilities of data custodianship

Amongst participating agencies and countries, it remains unclear as to who is responsible for maintaining datasets for IFWs:

> … it's a little bit about our traditional remits just being on the hazards information and so insurance companies and other areas are associated with damage and loss. And now … the challenge is accessibility to the data. So, we don't necessarily need to or want to become custodians of new data sets, we're just keen, if someone's got it organised and has it, to be able to … bring it together with our hazard information and our

Table 1
Interviewee codes.

Interview Code	Position	Classification	Location	Government Level
Agriculture/Rural NZ. A	Agriculture policy coordinator	Agriculture/Rural	NZ	National
Data Management Gov. NZ. Nat. A	Senior Resilience Advisor	Data Management	NZ	National
Data Management Private NZ. B	Geospatial Specialist	Data Management	NZ	Private
Data Management Research NZ. C	GIS Specialist	Data Management	NZ	Private
Data Management Private NZ. D	GIS Specialist	Data Management	NZ	Private
Data Management Gov. NZ. Nat. E	Head of Data	Data Management; Governance	NZ	National
EM. NZ. Reg. A	Director	Emergency Management	NZ	Regional
EM. NZ. Reg. B	Controller	Emergency Management	NZ	Regional
EM. NZ. Reg. C	Controller	Emergency Management	NZ	Regional
EM. NZ. Reg. D	Principal Science Advisor	Emergency Management	NZ	Regional
EM. NZ. Reg. E	Principal Advisor Strategy and Partnerships	Emergency Management	NZ	Regional
EM. NZ. Reg. F	GIS Lead	Emergency Management; Data Management	NZ	Regional
EM. Gov. NZ. Nat. G	Senior Hazard Risk Management Advisor	Emergency Management; Governance	NZ	National
EM. NZ. Reg. H	Emergency Management Advisor	Emergency Management	NZ	Regional
EM. NZ. Nat. I	First Responder	Emergency Management	NZ	National
EM. Gov. NZ. Nat. J	National Operations Manager	Emergency Management; Governance	NZ	National
EM. NZ. Reg. K	Regional Manager	Emergency Management	NZ	Regional
EM. NZ. Reg. L	Emergency Management Advisor	Emergency Management	NZ	Regional
EM. NZ. Reg. M	Group Controller	Emergency Management	NZ	Regional
Health NZ. Reg. A	Respiratory Doctor	Public Health	NZ	Regional
Hyd. Gov. NZ. Reg. A	Flood EWS Programme manager	Hydrology; Governance	NZ	Regional
Interview Code	Position	Classification	Location	Government Level
Lifelines NZ. Reg. A	Civil Engineer	Lifelines	NZ	Regional
Loss Modelling Research NZ. A	Economist	Loss Modelling; Research	NZ	Private
Met. Int. A	Science Manager	Meteorology	International	National
Met. Int. B	National Manager Disaster Mitigation Policy	Meteorology	International	National
Met. Int. C	Senior Policy Officer	Meteorology	International	National
Met. Int. D	Senior Social Scientist	Meteorology	International	National
Met. Int. E	Consultant Meteorologist	Meteorology	International	National
Met. NZ. F	Senior Meteorologist	Meteorology	NZ	National
Met. NZ. G	Communications	Meteorology	NZ	National
Met. NZ. H	Public Relations	Meteorology	NZ	National
Met. Int. I	Division Chief/Meteorologist	Meteorology	International	National
Met. Research NZ. J	Meteorologist	Meteorology; Research	NZ	National
Met. NZ. K	Senior Meteorologist	Meteorology	NZ	National
Met. Private NZ. L	Head Weather Analyst	Meteorology	NZ	Private
Risk Modelling NZ. A	Risk Modeller	Risk Modelling	NZ	National
Risk Modelling NZ. B	Risk Modeller	Risk Modelling	NZ	National
Risk Modelling NZ. C	Risk Modeller	Risk Modelling	NZ	National
Risk Modelling NZ. D	Risk Modeller	Risk Modelling	NZ	National

forecasting capability (Met. Int. B).

The responsibility and cost of collecting and storing HIVE data were concerns for participants. Many of the agencies' remits do not include data custodianship, and it would be a costly undertaking, with the uncertainty of maintaining funding (Met. Int. B; Met. NZ. F).

While the literature has pointed to Emergency Management (EM) agencies for collecting impact information (e.g., [44,70]), we found that the participating NZ-based EM agencies indeed collect impact information, but they often do not systematically collect it or store it (EM. NZ. Reg. A, B). These findings corroborate those of Crawford et al. [14], who found that EM agencies and councils in Aotearoa-New Zealand were not clear on who was responsible for collecting risk data. For example, regarding the NZ National Loss Database under development by the National Emergency Management Agency in Aotearoa-New Zealand (NEMA), our participant indicated that NEMA is not a designated data custodian in NZ, and as such, they have been grappling with learning proper data management protocols (EM. Gov. NZ. Nat. G). This raises questions around who is most suitable for managing and acting as the steward and/or custodian of the data.

Several data custodians were identified in passing during our interviews, which align with some that have been identified by LINZ [49], such as LINZ, the NZTA, and local councils. For example, a risk modeller who was involved in collecting building asset information for the 2011 Canterbury earthquake recovery described how maintenance responsibilities for these data were transferred to LINZ due to privacy concerns:

> because there's some personal information in the database … that we didn't pay attention [to] previously … but to protect us from now on, we say 'okay this is the data we give [to] LINZ, you guys take the data … and you … decide if you want to share the data or not' (Risk Modelling NZ. B).

Similarly, for the development and management of the NZ National Loss Database, NEMA has turned to Statistics New Zealand (typically referred to as Stats NZ, New Zealand's national statistics agency) for guidance on proper data management protocols:

Table 2
Coding paradigm summary(from Harrison et al., In Press).

Coding Paradigm Dimension	Description
Causal Conditions	A set of events that influence the phenomena or result in the appearance or development of a phenomena [77,82].
Phenomena	The subject or object under study [77].
Contextual Conditions	The specific set of conditions and characteristics surrounding the phenomena and resulting in action/interaction strategies taken to address the phenomena [77,82].
Intervening Conditions	Unexpected events or factors leading to action/interaction strategies (e.g., time, space, culture, socioeconomic status, technological status, history) [77,82].
Action/Interaction Strategies	Purposeful and deliberate acts taken to address the phenomena [77,82].
Consequences	Predictable or unpredictable, intended or unintended outcomes of the action/interaction strategies [77,82].

> Stats NZ … have helped us think about this, but it's their business. So, for example, we talked about data management, and they talked about, 'okay if you're holding that data then you need to run an integrity test, that your data hasn't become corrupted, and you do that every [so often]. And you've got enough backups' and all that … but we haven't got an explicit data management policy around ensuring it's not corrupt, its integrity … change controls, and all that tracking; that's not what we do (EM. Gov. NZ. Nat. G).

In addition to being the national statistics agency for Aotearoa-New Zealand, Stats NZ also became the lead agency for government-held data in 2017 [75]. In this leadership role Stats NZ acts as a facilitator to support government agencies in building their capabilities and data management practices [75]. Thus, their help in guiding NEMA towards proper data management practices for the National Loss Database aligns with their role as the lead for government data. The Stats NZ website[1] provides further guidance on principles for safe and effective use of data and analytics, data stewardship, data standards, open data, etc.

Several of the HIVE datasets that were identified by Harrison et al. [34] have been classed as fundamental geospatial datasets by LINZ and have an appointed, proposed, or suggested data custodian and steward. Table 3 presents the Suggested (S), Proposed (P), or Appointed (A) Stewards and Custodians of the HIVE data sets identified by Harrison et al. [34] from our interviews as designated by LINZ [49]. The results in Table 3 are based on an analysis of two LINZ documents regarding data custodianship (see [49,50]).

The results in Table 3 show that stewardship/custodianship for most of the underlying datasets for hazards, vulnerability, and exposure have been identified by LINZ and are either Suggested (S), Proposed (P), or Appointed (A), while there is a clear a gap in the stewardship/custodianship of impact data, as shown by the number of 'N/A' entries for these datasets. This, in conjunction with our interviews, shows the need for establishing data management protocols and practices for impact data, including identifying potential data stewards and custodians for these data, such that the data can be accessed by and shared with other relevant users.

3.2. Data access and sharing

Data access and sharing was the next phenomenon identified in our data analysis. The ES-GT coding paradigm was applied to understand the causal and intervening conditions, and action/interaction strategies for data access and sharing, as shown in Fig. 1. As discussed by Harrison et al. [34],[2] disaster/emergency events, technological advancements, and research were identified as the causal conditions to data collection and data access and sharing. For example, sharing data was required for the response to the 2019 Pigeon Valley fires in Nelson, NZ, yet organisational and technical issues impeded the data sharing process (Data Management Gov. NZ. Nat. A). However, as shown in Fig. 1, intervening conditions can inhibit data sharing and access while several action/interaction strategies have been identified as capable of addressing these intervening conditions. These conditions and strategies will be discussed next.

3.2.1. Organisational aspects of data access and sharing

Trust and distrust, and privacy and security were identified as organisational intervening conditions affecting data sharing. Building partnerships was identified as an organisational action/interaction strategy to address these intervening conditions. These will be discussed next.

3.2.1.1. Trust and distrust as intervening conditions. Trust is a key element to data use and access. While Harrison et al. [34] identified the importance of trust in the data for IFWs, here we found the need for trust between agencies to be an important condition for data access and sharing, as summarised by an NZ risk and data specialist:

> There's a lot of suspicion between institutions in New Zealand as to what people are doing things for and why and with this comes patch protection. This is an important point and that it inhibits risk awareness, collaboration and our risk management as a country (Data Management Private NZ. D).

The management of the NZ Flood Pics[3] crowdsourcing platform and access to its resulting data is an example of an initiative established to avoid suspicion and lack of institutional trust, according to one of our interviewees (Data Management Private NZ. D). They described that NZ Flood Pics was developed independently from any institutions, and there is an aversion to tying the platform to any single institution even though that would make available the resources needed to sustain the platform. This aversion stems from the need for the data to remain open and separate from any "ulterior motives" (Data Management Private NZ. D). They indicated that institutionalising the platform may give the impression that there is an agenda with the use of the data, which could make people wary to contribute to it. At the time of conducting this interview, the costs and resources needed to sustain the platform remained such that the participant was seeking collaborating support and buy-in from multiple sectors with the requirement of keeping the data openly accessible. An update has since been provided by this participant that NZ Flood Pics is now in the process of being institutionalised with the Natioanl Institute for Water and Atmospheric Research (NIWA; a Crown Research Institute in New Zealand) with an agreed set of principles for how the data will remain open and accessible for "anybody to add value" (Data Management Private NZ. D).

Institutional involvement and open access to and sharing of citizen science data are growing areas of interest in citizen science research. The type of organisation involved in citizen science projects appears to influence people's willingness to participate and contribute their data [3]. For example, Martin et al. [51] found that contributors to a marine citizen science project in Australia showed a very high willingness to share data with research organisations, but less so with private research companies or consultants. Additionally, contributors seem to care about how the data they contribute is shared: Ganzevoort et al. [27] found that surveyed citizen scientists do no support unconditional data sharing, rather their acceptability of sharing the data with third parties depends on the goals of the data user. Moreover, Groom et al. [31] argue that the motivations of citizen scientists to contribute their data should align with the accessibility of the data for other uses. Thus, it is important to invest in data policies and transparency efforts to protect the interests of the contributors and ensure their continued engagement [3].

Participants indicated that some agencies who collect impact data were also found to be averse to sharing the data due to its sensitive nature and distrust in how such data could be used (Met. Int. D; Risk Modelling NZ. A; Loss Modelling Research NZ. A). As one loss modelling participant from Aotearoa-New Zealand outlined, not all agencies are willing to publicly share their data, such as a public insurance group that formed after the 2010–2011 Canterbury earthquake sequence (Loss Modelling Research NZ. A). As such, there is no guarantee that government/public organisations will want to, or can, make any of their data publicly available (Loss Modelling Research NZ. A).

This could be due to the sensitive nature of the data (Met. Int. D; Risk Modelling NZ. A). Certainly, in Aotearoa-New Zealand there are concerns around how releasing impact information could influence property values (Risk Modelling NZ. A). In Argentina, our participant described how a provincial government would not share their impact data with the National Meteorological Service (NMS) because of the political nature of the data:

[1] https://www.stats.govt.nz/about-us/data-leadership. Accessed 20 December 2021.

[2] The results of Harrison et al. [34] are presented in a similar fashion using the ES-GTM Coding Paradigm to analyse the causal conditions, intervening conditions, and action/interaction strategies pertaining to the Data Collection phenomenon. As such, a similar figure is presented here, but pertaining instead to the Data Access and Sharing phenomenon.

[3] www.nzfloodpics.co.nz. Accessed 20 December 2021.

Table 3
Suggested (S), Proposed (P), or Appointed (A) Stewards and Custodians of the HIVE data sets identified by Harrison et al. [34] from our interviews as designated by LINZ [49]. N/A is used for datasets that were not proposed as fundamental datasets (note that any person or agency can propose a fundamental geospatial dataset [49]), and thus a steward and custodian was not identified. The number of N/A entries demonstrates a lack of direction for managing impact data.

	Dataset	Status	Steward	Leadership Custodian	Delivery Custodian
Hazard Data	Weather stations (rain gauges, anemometers, etc.)	N/A	N/A	N/A	N/A
	Radar data	N/A	N/A	N/A	N/A
	Satellite imagery & observations	Fundamental, Not evaluated	LINZ (A)	LINZ (S), NZDF (S), TAs (S), Police (S)	LINZ, NZDF, TAs, Police, MfE, Landcare (S)
	River height and flow gauges	Not evaluated	Steward Committee (S) or MPI (S), MfE (S)	MfE (S)	RCs (S)
	Float gauges/Sea level data	N/A	N/A	N/A	N/A
	River networks	Fundamental	Steward Committee (S) or MPI (S), MfE (S)	MfE (S), LINZ (S)	NIWA (S)
	Vertical Rain Radar	N/A	N/A	N/A	N/A
	Regionwide floodplains	Not evaluated	Steward Committee (S) or MPI (S), MfE (S)	MfE (S), LINZ (S)	NIWA (S), GNS (S), RCs (S), TAs (S)
	Overland flow paths	N/A	N/A	N/A	N/A
	Coastal inundation Maps/Hazards	Not evaluated	Steward Committee (S) or MPI (S), DoC (S)	MfE (S)	RCs (S), GNS (S)
	Pollen Counts	N/A	N/A	N/A	N/A
	Slope	N/A	N/A	N/A	N/A
	Camera feeds	N/A	N/A	N/A	N/A
	Social media (Tweets, Facebook post comments)	N/A	N/A	N/A	N/A
	Crowdsourcing (e.g., volunteer rain gauges, NZ Flood Pics)	N/A	N/A	N/A	N/A
	Dataset	Status	Steward	Leadership Custodian	Delivery Custodian
Impact Data	Social media (Tweets, Facebook post comments, SnapChat)	N/A	N/A	N/A	N/A
	Crowdsourced Photos via Story Maps (e.g., NZ Flood Pics)	N/A	N/A	N/A	N/A
	Crowdsourcing/Public Reporting	N/A	N/A	N/A	N/A
	Red Cross Chained Crowdsourcing	N/A	N/A	N/A	N/A
	Emergency call centre reports	N/A	N/A	N/A	N/A
	Community volunteer radio calls	N/A	N/A	N/A	N/A
	Damage surveys	N/A	N/A	N/A	N/A
	Media reports	N/A	N/A	N/A	N/A
	Tacit knowledge, experience, intuition	N/A	N/A	N/A	N/A
	Health & Injury Data	N/A	N/A	N/A	N/A
	Wellbeing Surveys	N/A	N/A	N/A	N/A
	Post-event interviews and surveys	N/A	N/A	N/A	N/A
	Insurance claims	N/A	N/A	N/A	N/A
	“Boots on the ground”	N/A	N/A	N/A	N/A
	Lifelines Sectors (e.g., power companies, NZTA)	N/A	N/A	N/A	N/A
	Situational Reports	N/A	N/A	N/A	N/A
	Post-event reports	N/A	N/A	N/A	N/A
	Operations Reports (Council)	N/A	N/A	N/A	N/A
	Flood event reporting	N/A	N/A	N/A	N/A
	Injuries and fatalities (e.g., cause of death)	N/A	N/A	N/A	N/A
	Cultural and heritage/historical impacts	N/A	N/A	N/A	N/A
	Impact Model outputs	N/A	N/A	N/A	N/A
	NZ National Loss Database	N/A	N/A	N/A	N/A

	Dataset	Status	Steward	Leadership Custodian	Delivery Custodian
Vulnerability Data	Vulnerability Assessment and Risk Modelling Outputs	N/A	N/A	N/A	N/A
	Asset information - Building footprints	Fundamental	LINZ (A)	MBIE (S)	TAs (S), NZFS (S), MBIE (S)
	Asset information - Historically and Culturally Significant Sites	Not evaluated	Steward Committee (S) consisting of LINZ (S), LGNZ (S), Emergency Services (S)	LINZ (S), LGNZ (S)	LINZ (S), TAs (S), Private Sector (S)
	Building damage assessments		N/A		
	Census data - meshblocks	Fundamental	Stats NZ	Stats NZ	Stats NZ
	Tacit knowledge, experience, intuition	N/A	N/A	N/A	N/A
	Lab-based experiments	N/A	N/A	N/A	N/A
	Health Data, New Zealand Health Survey	N/A	N/A	N/A	N/A
	Soil/land stability	Fundamental	No Steward	LINZ (S), GNS (S), Landcare (S)	LINZ (S), GNS (S), Landcare (S)
	Infrastructure - NZ Road Network	Not evaluated	Ministry of Transport	NZTA (P)	NZTA (P)
	Infrastructure - Council roads	Not evaluated	Ministry of Transport	LGNZ (S)	TAs (S)
	Infrastructure - Water	Not evaluated	Steward Committee (S) or MPI (S), MfE (S)	MfE (S), LINZ (S)	NIWA (S), LINZ (S), RCs (S), TAs (S)

	Dataset	Status	Steward	Leadership Custodian	Delivery Custodian
Exposure Data	Asset information - Building footprints	Fundamental	LINZ (A)	MBIE (S)	TAs (S), NZFS (S), MBIE (S)
	Asset information - Historically and Culturally Significant Sites	Not evaluated	Steward Committee (S) consisting of LINZ (S), LGNZ (S), Emergency Services (S)	LINZ (S), LGNZ (S)	LINZ (S), TAs (S), Private Sector (S)
	Infrastructure - NZ Road Network	Not evaluated	Ministry of Transport	NZTA (P)	NZTA (P)
	Infrastructure - Council roads	Fundamental	Ministry of Transport	LGNZ (S)	TAs (S)
	Infrastructure - Power - Electricity	Not evaluated	No Steward	Transpower (S)	Transpower, Lines Companies
	Infrastructure - Utility Networks	Not evaluated	No Steward	MCDEM/NEMA (S)	Utility Companies (S)
	Infrastructure - Water	Not evaluated	Steward Committee (S) or MPI (S), MfE (S)	MfE (S), LINZ (S)	NIWA (S), LINZ (S), RCs (S), TAs (S)
	Census data - meshblocks	Fundamental	Stats NZ	Stats NZ	Stats NZ
	Population movement via cell phone data	N/A	N/A	N/A	N/A
	Tacit knowledge, experience, intuition	N/A	N/A	N/A	N/A
	Topographical data, e.g. digital elevation models	Not evaluated	No Steward	MfE (S), LINZ (S)	Landcare (S), LINZ (S)
	Land-use and planning zones	Not evaluated	No Steward	LGGA (S), LGNZ (S)	TAs (S), RCs (S)
	Land-use maps	Fundamental	No Steward	MfE (S)	MfE (S)
	Community events	N/A	N/A	N/A	N/A

The acronyms in Table 3 are as follows: Land Information New Zealand (LINZ), New Zealand Defence Force (NZDF), Territorial Authorities (TAs), Ministry for the Environment (MfE), National Institute of Water and Atmospheric Research Limited (NIWA), Ministry of Primary Industries (MPI), Institute of Geological and Nuclear Sciences Limited (GNS Science), Regional Councils (RCs), Department of Conservation (DoC), Ministry of Business, Innovation and Employment (MBIE), Local Government New Zealand (LGNZ), Statistics New Zealand (Stats NZ), New Zealand Transport Agency (NZTA), National Emergency Management Agency (NEMA, formerly MCDEM), Local Government Geospatial Alliance (LGGA)

> I was working with the province of [redacted] … and we implement[ed] this [data collection] form as a final project, and when I [said] 'okay, I want the data' they [told] me 'okay, we will give you the infrastructure data but no data about deaths' … And I was like 'hey, no. That's not fair.' Why? Because it's political data! Who live and who die during a storm: that's political data, because it has to do with vulnerability and people here [are] very vulnerable. That's why I say that impact data is political data (Met. Int. D).

This finding aligns with those from Harrison and Johnson [33], where Canadian emergency managers showed concern about displaying heavily damaged areas online via crowdsourcing platforms for emergency response. However, as shown in the above quote, the political nature by which the impact data in Argentina is perceived adds another layer beyond simply showing concern for the privacy and security of people and assets during an emergency. Viewing impact data as a threat to how government response agencies and their response capabilities are perceived indeed introduces a political element that inhibits the global movement for open and collaborative data sharing for improved DRR.

The consequences of restrictive data access and lack of information sharing for DRR can lead to disastrous consequences, as was seen in the USA following the landfall of Hurricane Katrina in 2005 [68]. Yet, our findings show that data creators and users remain reluctant to share critical

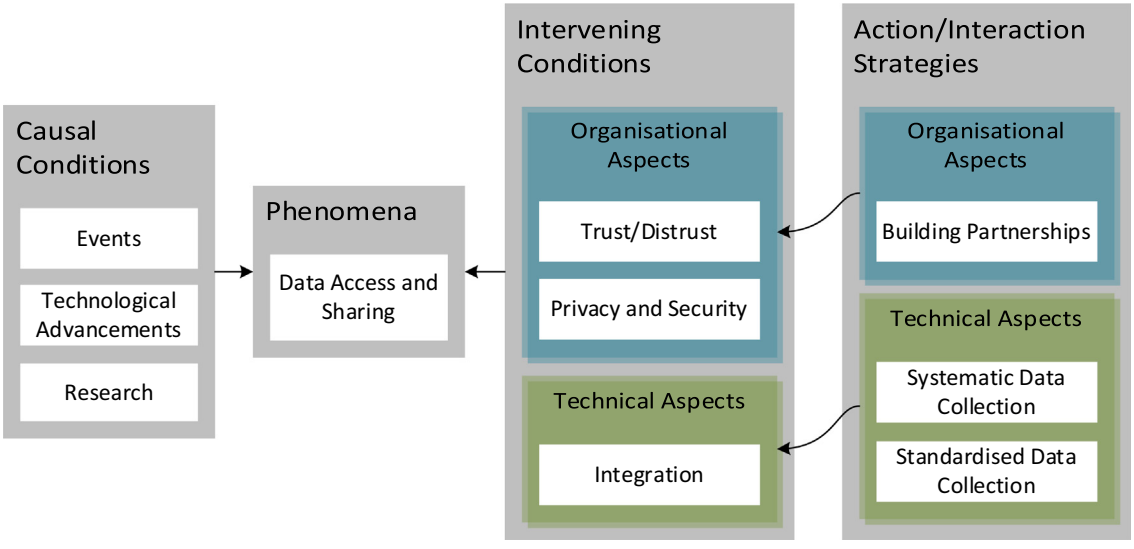

Fig. 1. Summary of findings relating to the causal conditions, intervening conditions, and action/interaction strategies relating to data access and sharing, identified using the ES-GTM coding paradigm. Blue boxes represent organisation aspects and green boxes represent technical aspects.A socio-technical lens was applied to the analysis to identify both organisational aspects to the intervening conditions and action/interaction strategies and the technical aspects. The following results are separated accordingly, and further partitioned into intervening conditions (i.e., Trust/Distrust, and Privacy and Security as organisational intervening conditions, and Integration as a technical intervening condition), and action/interaction strategies (i.e., Building Partnerships as an organisational action/interaction strategy, and Systematic and Standardised Data Collection as technical action/interaction strategies).

information. In addition to the concerns around the political nature of the data as described above, this aversion to sharing may be due to inter-agency competition over resources, influence, and autonomy [68], and/or loss of control over the datasets [6].

Trust is an essential factor in multi-agency collaboration and data sharing, especially for disaster response [21]. Our findings further illustrate the importance of trust to facilitate data access and sharing through interagency collaboration for DRR [42]. The importance and value of opening and sharing disaster-related data cannot be denied, and it is possible to establish open data access and sharing for DRR. For example, local, provincial, and national agencies, and regional and national academic and research institutions in Argentina worked together to establish an open data platform for flood impact reduction, "with a view to socializing knowledge for early alerts" ([15], p. 86). Thus, agencies must continue to build and nurture trust between each other to facilitate data and information sharing.

Traditional media outlets may be one party not tied to the political influence and privacy and security concerns of sharing data, and play a major role in disseminating information during a disaster [30,59]. For example, in Aotearoa-New Zealand, the MetService usually has "a conversation with media" about their official warning message and provides examples of impacts along with the warning message to add meaning and context to the warning. The media then passes on this information to the public (Met. NZ. G, K).

Media outlets and reports can be a timely data stream for information during a disaster [59]. They can even provide new information that might not otherwise be picked up or observed elsewhere. For example,

> there might be a report of … a motorcyclist blown off a piece of road or something. But there might not be any weather observations for miles in any direction that support that. So, then you have to go and look for corroborating evidence somewhere else, and how much do you trust the source? (Met. NZ. K).

However, as this example suggests, while media reports can bring new information to light, the new information still needs to be verified, as it might not always be accurate or true. Media outlets are both heavily reliant and influential on perceptions of trust and distrust during disasters [57]. In another example, a regional EM agency in Aotearoa-NZ received crowdsourced reports on their public online story map of a van "stuck in the centre of the Hokitika River" (EM. NZ. Reg. F). The media picked up this report and publicised that "there's people trapped" (EM. NZ. Reg. F). The van was empty, and the EM agency had to re-upload the report themselves to include a note that the van was empty (EM. NZ. Reg. F).

The literature indicates that agencies elsewhere have reported difficulties with communicating with media outlets e [4,59]. In Aotearoa-New Zealand, the continuous conversations between the NZ MetService and the media described above exemplify a working relationship that ensures a unified message for informing people. In another example, the media provided "quite active and quite positive support" in the response and evacuation of a large-scale flood in Edgecumbe, Bay of Plenty by providing ample media coverage of the event and of the messages issued by the EM agency (EM. NZ. Reg. A). For media outlets and their resulting reports to be effectively used by their audiences, it is thus critical for them to build trusted relationships with those audiences, including members of the public, hydrometeorological services, and EM agencies. This could include developing a process or protocols for sharing data and information effectively.

3.2.1.2. Building partnerships as an action/interaction strategy. While NMSs are not typically responsible for collecting non-meteorological data, EM and flood management agencies, amongst others, collect or produce various types of impact data for their own purposes. Findings from the interviews, in support of existing literature (e.g., [36,84]), suggest that either formal or informal partnerships support data sharing for DRR. Continued collaboration to build and nurture partnerships has a positive relationship with trust [42], an important factor for sharing data. Under the NHP, previously describbted in section 1.2.1 [36], the UK MetOffice can access useful datasets such as traffic count data from the transportation agency, for their impact models (Met. Int. A;).

In Aotearoa-New Zealand and other participating countries, no such formal partnership was found to exist that is comparable to the NHP in the UK. However, evidence of informal partnerships was found in Aotearoa-New Zealand and Australia. In both Aotearoa-New Zealand and Australia, NMS and EM officials frequently contact each other informally during an event to exchange more targeted forecasting information such as levels of uncertainty, and worst-case scenarios to help with planning responses (Met. Int. B; Met. NZ. F, K; EM. NZ. Reg. A, B, C, D, E, F; [35]). For example, as reported by Harrison et al. [35], the NZ MetService works together with local and regional EM groups and hydrologists to determine the most appropriate warning level. These informal partnerships are particularly useful for information-sharing and decision-making on-the-fly during an event.

A need remains for more formal partnerships to facilitate data sharing after response events (Risk Modelling NZ. A). However, progress in this space will be slow:

> there's lots of talk about data sharing and I think there's a general attitude in New Zealand moving towards greater collaboration, greater sharing. [But] a sort of central repository for any of this stuff within the next decade is absolutely not going to happen, or if ever … It's hard to get people to work together (Risk Modelling NZ. A).

The participant listed data ownership and proprietary licensing as key limitations to sharing data. Perhaps in the context of sharing HIVE data via a central repository as mentioned by the risk modeller (Risk Modelling NZ. A), progress will indeed be slow as this requires more in-depth understanding and legal groundwork to establish data ownership rights and protection of proprietary data (e.g., [11]; Risk Modelling NZ. A). However, like the informal partnerships between the MetService, EM groups, and council hydrologists to share hydrometeorological information for warnings, another informal partnership has been established to fill a gap in EM practice in Aotearoa-New Zealand, the NZ Geographic Information Systems for Emergency Management (NZGIS4EM) group.

The NZGIS4EM group formed in the mid-2010s to boost the use of geospatial tools, such as Geographic Information Systems (GIS) within the EM sector (EM. NZ. Reg. H; [34]). NZGIS4EM is a grassroots community of GIS specialists and EM practitioners in Aotearoa-New Zealand that work together to share data and tools during responses and to innovate the use of geospatial technologies for EM (EM. NZ. Reg. H; Data Management Private NZ. B; [34]). The community was formed from the leadership of one skilful individual who identified the need for geospatial innovation in the NZ EM sector, to enhance practices from relying on paper maps to using modern tools and technology (Data Management Private NZ. B).

The NZGIS4EM is credited with fostering a community of practice within the EM and GIS sectors, where relationships across agencies have been built and strengthened for a more coordinated disaster response effort (EM. NZ. Reg. H; Data Management Private NZ. B). In turn, this has driven innovation, knowledge sharing, and data sharing across Aotearoa-New Zealand (EM. NZ. Reg. H; Data Management Private NZ. B). Direct outcomes of this group's work are seen in the recent *Director's Guideline for Civil Defence Emergency Management Groups [DGL 22/20]* [60] and *Technical Standard [TS05/20] National Impact Assessments Data Set and Dictionary* [62], published by NEMA. In these documents, the use of GIS is heavily referenced, and NZGIS4EM aided in defining the standards presented in the *Technical Standard [TS05/20] National Impact Assessments Data Set and Dictionary* ([62]; Data Management Private NZ. B).

Our findings suggest that informal partnerships are developed to fulfil an immediate need, such as communicating hydrometeorological information for warning decision-making or building a community of practice for coordinated disaster response. This finding aligns with the ad hoc informal partnerships that formed in the response and recovery to the 2010–2011 Queensland floods, where such partnerships formed between public and private agencies for information sharing [5]. Furthermore, interorganisational networks facilitated by groups like the NZGIS4EM can be voluntary or mandated [43]; in

the case of the NZGIS4EM group, it is a voluntary effort. Success factors of such networks have been identified as effective communication, trust and social capital, and learning and adaptation [43].

Formal partnerships appear to be less common, and not as easy to establish, as indicated previously (Risk Modelling NZ. A), particularly for severe weather hazards. However, formal partnerships have been developed in Aotearoa-New Zealand in the form of science advisory panels for natural hazard perils, such as the New Zealand Volcanic Science Advisory Panel [61], and the New Zealand Tsunami Advisory Group. The New Zealand Volcanic Science Advisory Panel works with area-specific volcanic advisory groups to coordinate planning for volcanic activity [61]. These groups were formed from a specific need that was either identified from local/national or international events (EM. Gov. NZ. Nat. J), to better communicate science advice by bringing the expertise from various scientific agencies together [20]. For example, the New Zealand Tsunami Advisory Group was established in response to the 2011 Tōhoku and 2004 Indian Ocean earthquakes and tsunami (EM. Gov. NZ. Nat. J). These groups differ from the UK NHP in that practitioners are not formally included in them and some of the groups' roles in response and providing formal advice are unclear. Partnerships and multi-agency collaboration are not new concepts in the EM literature (e.g., [65]). It is promising to see these growing examples of successful partnerships both within and outside of Aotearoa-New Zealand, be it formal and informal. However, more clarity is needed to establish the roles of these NZ-based groups for response and formal advice.

Strategies for building and nurturing partnerships and collaboration include networking (EM. Gov. NZ. Nat. J), professional development (EM. NZ. Reg. K; [21]), cohabitation [36], and multi-disciplinary collaboration (Risk Modelling NZ. C; [28]), which may or may not be supported by funding and top-down mandates (EM. Gov. NZ. Nat. J; [67]). Participants indicated that a mix of both bottom-up and top-down approaches to building and nurturing partnerships is applicable in the Aotearoa-New Zealand context (EM. Gov. NZ. Nat. J). For example, cohabitation between agencies like the MetService, CDEM Groups, and local/regional councils can be organised from the bottom-up between the agencies in question. However, some political direction such as a national mandate might be more effective at inciting nation-wide cohabitation practices (EM. Gov. NZ. Nat. J). Further exploration of these strategies will be explored in future research.

3.2.1.3. Privacy and security as an intervening condition. When it comes to sharing data for emergency response purposes, our participant from Fire and Emergency New Zealand (FENZ) identified the importance of protecting the response data. Much of their response data comes from NZ Police, who have very structured and careful security systems protecting their information (EM. NZ. Nat. I). As such, parties are working with the Privacy Commissioner to show that they can ensure the appropriate controls to protect the information, and in turn, there are also cultural challenges around the views of sharing information (EM. NZ. Nat. I). Our FENZ participant indicated that it is a matter of knowing staff members' behaviours and educating staff on why it is important to keep the data safe, while also safely sharing the information for effective response.

Safe and secure mechanisms for sharing the data are needed but are not always feasible. For example, our participant from Argentina indicated that they set up a Google Form to facilitate standardised data collection and sharing between the NMS and local government agencies, but they "have concerns … because … it is sensitive data [and] I don't trust … sending information through Google" (Met. Int. D). However, Google Forms was the most easily accessible tool that the local government agencies could handle (Met. Int. D). This demonstrates the need to have controls in place to maintain privacy and ensure data security.

3.2.2. Technical aspects of data access and sharing

Challenges around data integration were identified as a technical intervening condition affecting data sharing. Systematic Data Collection and Standardised Data Collection were identified as technical action/interaction strategies to address this intervening condition. These will be discussed next.

3.2.2.1. Data integration as an intervening condition. Sharing data is only successful when the data can be integrated seamlessly into existing systems and practices [56]. Findings from Harrison et al. [34] show that a wide variety of HIVE data for severe weather events exists. In many cases, the challenge lies not in identifying the data sources but in integrating all sources and types of data in a meaningful way (NMS. Int. A, E; NMS. NZ; EM. NZ Regional. A, B, E). This is summarised by an NZ risk modeller, "although we all complain about a lack of data, a lot of the time, there is quite a bit of data out there that could be used and isn't being used very well" (Risk Modelling NZ. A). For example, this participant identified struggles with integrating building data, which is typically stored as spatial point data, with meshblock data, which is stored as spatial polygons. They stated that matching these point and polygon data together

> can be the bigger barrier than the fact that the data does or doesn't exist. Because … it turns out it's really not easy to put those points in a polygon because … there's no basic way of doing that, it's complicated (Risk Modelling NZ. A).

Furthermore, our UK-based participant described how they would like to see

> an integration of different approaches [like] the use of satellite, the use of social media, the use of citizen science, the use of media, and the integration of media to help understand better the differences and the causes for different types of impact (NMS. Int. A).

Some data integration methods have been successfully implemented. For example, the NZ MetService receive council rainfall data and share warning data files to integrate into hydrological models. In Aotearoa-New Zealand, the West Coast EM agency primarily works online so they can share information in near-real-time with other agencies. But this is not standard practice across the country; gaps still exist in developing formal systems for data sharing and integration. A regional EM official elaborated on their challenges of linking up and integrating various data sources:

> I would like to see … some research in understanding what are the tools and systems that can be used for this? Because on one hand … if you sit around and everyone goes 'yeah, … we must share data' and … if we're going to plan for the future and everyone, different agencies hold different data about the same event, but how we're sharing that data? So, what is the system to do that? (EM. NZ Regional. A).

The Common Operating Picture (COP) is a solution currently under development in Aotearoa-New Zealand to allow cross-agency intelligence and data sharing during a response. The COP, a recommendation made following the 2010–2011 Canterbury earthquakes and other notable events (see [78]), is based on the idea of "everyone contributing to the scenario so that they've got to share, so that everyone's got access to that information" (EM. NZ. Reg. A); in other words, it is "a graphical visualisation of all the data available to make a decision" (Data Management Private NZ. B).

Phase one of the NZ COP programme began in late 2019 led by NEMA, when agencies involved identified the core national datasets needed for EM, and brainstormed how some of those datasets are shared, particularly geospatial datasets (EM. NZ. Reg. H). This required agencies to collaborate to identify different needs, highlighting the need for building trust and partnerships between agencies to facilitate data sharing.

Other solutions have been proposed and developed for improving data interoperability for integration. Horita et al. [38] developed a spatial decision support system (DSS) to integrate official and unofficial data for flood risk management in Brazil, showing that integration "provides more complete, accurate and updated information about the situation in the affected areas" ([38], p. 91).

Impact-based decision support systems (IDSS) offer a way for warning services to make effective decisions. An IDSS is "the provision of relevant information and interpretative services that enable partners to prepare for and respond, as planned, to extreme weather, water, and climate events

for the protection of lives and livelihoods" ([80], p. 1928). In a case study comparison of two historic severe winter weather events in the USA with and without a formal IDSS, the IDSS was found to enable quicker and more complete forecast updates, such that emergency managers could relay information to appropriate agencies to take mitigative actions [40]. The IDSS also allowed for improved crafting of public and partner messaging, and for preparing public officials to decide to shut down infrastructure.

Similarly, an integrated analysis of social vulnerability to extreme precipitation in Colorado was carried out by Wilhelmi and Morss [83] using Geographic Information Systems (GIS). The process involved integrating radar-derived rainfall data and watershed boundaries with national census data and historical impact data. Challenges were faced with the differences in spatial-temporal scales between meteorological and social datasets, as well as the various formats in which the meteorological data were available [83].

3.2.2.2. Systematic data collection as an action/interaction strategy. Systematic data collection is a need highlighted by many participants as an action/interaction strategy for better data sharing and integration. Non-systematic data collection occurs when data is collected in various formats and stored in different places (e.g., [52]). Thus, we refer to systematic data collection as having a system in place to process data from raw state to a usable format and storing the data in one place for easy access.

Our participants indicated that systematic data collection would support evidence-based planning and decision-making for warnings and planning (Met. Int. A; Met. NZ. F; EM. NZ. Reg. B). For example, our participating UK-based NMS official highlighted the need for systematic impact, exposure, and vulnerability data collection to be able to understand the causes of impacts with empirical evidence and to be able to compare different impact models (Met. Int. A). In Aotearoa-New Zealand, a lack of systematic data collection severely impacted the organisation of intelligence and data gathered from event responses. For example, "back in 2011 [Canterbury earthquakes] … the capture of the data was so unstructured" (Data Management Gov. NZ. Nat. A); photos of buildings and letterboxes were not associated with dates or addresses, nor were they associated with damage and impact assessment forms used to capture information about the person and/or building (Data Management Gov. NZ. Nat. A). Consequently, an individual was "employed … for 18 months, just to take that photo and that building form and that welfare form and try to bring together a file on that family" (Data Management Gov. NZ. Nat. A). Had the data been collected in a more systematic way, "that information … would have been more informative at the time of the response and recovery" (Data Management Gov. NZ. Nat. A). Furthermore, systematic data collection would allow the sector to learn from past events and forecast potential future events by identifying impacts from events with similar meteorological signatures (Met. NZ. F; EM. NZ. Reg. B).

The COP previously mentioned provides a streamlined system for collecting, sharing, and managing impact data. However, much of this data does not have a shelf life beyond its initial purpose of building situational awareness for decision making during a response, because "from a Civil Defence perspective, whether it's local or regional, we don't need to keep the data, really. We'd probably keep it for two years and then say right, we're going to dispose of it because we don't need it" (EM. NZ. Reg. H). This also applies to welfare/wellbeing assessments, which are "very challenging, because there is a lot more private and personally identifiable information collected" (EM. NZ. Reg. H). As such, the EM agency will "probably … be even more aggressive about deleting that information once the event is over, to protect the people's privacy" (EM. NZ. Reg. H).

3.2.2.3. Standardised data collection as an action/interaction strategy. Standardised collection of data was another need highlighted by many interviewees. Standardised data collection facilitates systematic data collection by providing a set of standards at which the raw data is collected such that it can be seamlessly integrated into a database with minimal processing [16,26]. Standardised data collection would ensure all data is collected consistently for rigour and comparability [16,26]. Our interviewees identified a need to be able to compare datasets and warnings across countries and regions, such as in Europe (Met. Int. E). Likewise, data collection practices within Aotearoa-New Zealand, Argentina, and Australia differ regionally, making it difficult for regions to share data. In Australia, EM agencies collect post-event impact assessments, but the Australian NMS official indicated that this data lacks necessary fields for forecasting purposes (Met. Int. E). In Argentina, the NMS is working with EM agencies to build a process for collecting standardised impact data using Google Forms to benefit both agencies; the EM agencies will have trustworthy data, while the meteorological service will have data to support IFW implementation (Met. Int. D).

Our investigation into Aotearoa-New Zealand practice showed that several types of standard data collection forms are available for different purposes, whereby the standards/forms were designed by different agencies for various uses. For example, in 2006, the Hawke's Bay Regional Council commissioned the development of *Templates for Consistent Hazard Event Reporting* (herein referred to as the *Template*) with a focus on capturing the impacts of the hazard for use by EM agencies for research, risk modelling, and developing a hazards and impacts database [22]. Standardised data collection provided from this template would better facilitate the organisation and storage of impact and hazard data for further use and analysis. However, it is unclear whether this form is used by EM agencies or councils across Aotearoa-New Zealand, as no participants identified it as a resource that they use, yet it has potential for development going forward.

NEMA published an *Impact Assessments Director's Guideline for Civil Defence Emergency Management Groups* outlining the preparation requirements for conducting effective and efficient rapid impact assessments by response agencies to enable a coordinated approach across multiple agencies (see [60]). This document identifies the agencies responsible for conducting impact assessments for various purposes and at various phases. For example, EM agencies or local authorities are responsible for planning rapid impact assessments, while FENZ is "likely to be one of the first responding agencies to conduct a rapid impact assessment" ([60], p. 15) due to their specialised capabilities for collecting and sharing field data [60]. NEMA also provided forms for completing an initial situation overview, initial damage assessment, and impact report form. These assessments support response planning and coordination (EM. NZ. Reg. H). Furthermore, a companion document called the *Technical Standard [TS05/20] National Impact Assessments Data Set and Dictionary* [62] provides more technical information to support the consistent collection and recording of impact assessment data for easy cross-agency sharing and integration.

Our participants identified welfare needs assessments as another form of impact assessment (EM. Gov. NZ. Nat. G; EM. NZ. Reg. H; Data Management Gov. NZ. Nat. A; Data Management Private NZ. B), focusing on "understanding the needs of people affected by an emergency" ([55], p. 1). Guidelines have been published outlining the welfare needs assessment process (see [55]). These guidelines indicate that data is collected using "customised [EM agency]/local authority forms" ([55], p. 11).

For the built environment, the Ministry for Business, Innovation and Employment (MBIE) published field guides, assessment forms, and other learning resources for rapid building damage assessments for flooding, earthquakes, and geotechnical hazards such as landslips (see [54]). These resources are an outcome of lessons learned from the 2010–2011 Canterbury earthquake sequence, the 2011 Nelson storm, and the 2016 Hurunui/Kaikoūra earthquake, and other international events [53]. These assessments are primarily used by councils via contracted building engineers to assess the building and land safety and usability immediately after an earthquake or flood (Risk Modelling NZ. B; EM. NZ. Reg. H; [54]), but are not suitable for impact/risk modelling because they are not designed for this purpose and are not sufficiently comprehensive (Risk Modelling NZ. B).

Alternatively, our risk modelling participant indicated that developing a "master building database" containing building attribute data pre- and post-disaster would be "ideal" (Risk Modelling NZ. B). The participant envisions the database holding building data for all purposes, populated before an event, and updated with damage information to the respective buildings

using a unique identifier post-disaster (Risk Modelling NZ. B). Efforts on this project are currently underway at GNS Science in Aotearoa-New Zealand (see [48]).

The above assessments can be completed on paper, as has traditionally been done. However, a recent technological overhaul of the NZ CDEM sector (Data Management Private NZ. B) has introduced new tools for streamlining the collection and integration of these datasets (EM. NZ. Reg. F; EM. NZ. Reg. H; Data Management Private NZ. B). Much of the system has become location-based (Data Management Private NZ. B) using GIS technology [60]. For example, the "welfare system [has] moved from being quite a database and table-based system to a location-based system" (Data Management Private NZ. B), and now utilises tools like Survey123[4] for welfare needs assessments (EM. NZ. Reg. H). The West Coast example outlined by Stowell [76] provides more detail on how GIS has been used to streamline the CDEM impact assessment process.

Outside of impact data and the CDEM sector, other agencies have developed their own applications for conducting standardised information. For example, the Real-time Individual Asset Attribute Collection Tool (RiACT) was developed by risk modellers to capture real-time, geolocated, standardised asset information, such as building attributes (Risk Modelling NZ. B; [47,48]). The goal of this tool is to support an exposure data development framework whereby exposure data is systematically collected and stored for improved access, management, and use (Risk Modelling NZ. B; [47,48]).

While various standardised forms have been developed to capture hazard and impact data for various purposes, it would be beneficial to continue the systematic process of integrating the resulting data into a data repository for ease of access, sharing, and use beyond its initial purpose, depending on licensing and proprietary restrictions (e.g., [11]). Global efforts in the hydrometeorological hazard space are underway for building data repositories. For example, the HIWeather Value Chain Project under the World Weather Research Programme (WWRP) is currently building a catalogue of hydrometeorological events and their impacts to evaluate the end-to-end warning value chain [37]. Additionally, the World Meteorological Organisation (WMO) has established an initiative for cataloguing hazards and events through its members [19].

Strategies for building an integrated and multi-disciplinary data collection approach rely, again, on building and nurturing partnerships and collaboration. Collaboration allows data collectors and users from various disciplines to jointly define and scope problems for which the data is being collected, and identify the data types that are of interest to the problem [28]. For example, Harrison et al. [35] identified the need for including social scientists when designing post-impact assessments for risk modelling such that the modelling can extend into social and cultural impacts. For the aforementioned HIWeather Value Chain Project, an international multi-disciplinary task team of social scientists, meteorologists, and risk scientists was formed to co-develop the data collection template for the event catalogue [37]. Consideration of emergent technology would also help with identifying efficient data collection and integration tools, such as GIS-based technology (e.g., Survey123), mobile devices, unmanned aerial vehicles (e.g., drones), etc. [46,85].

4. Conclusions and limitations

This exploratory study built further understanding around the management, acquisition, and sharing of hazard, impact, vulnerability, and exposure (HIVE) data for severe weather hazards in New Zealand, towards supporting Sendai Framework priorities and implementing Impact Forecasts and Warnings (IFWs). While the qualitative nature of data collection and analysis herein limits the generalisability of results beyond the interviewees, this approach offers an in-depth understanding of a problem not readily available from quantitative approaches, which is appropriate for an exploratory study such as this [9,58,66].

We employed a socio-technical lens to our analysis to identify the organisational and technical intervening conditions and action/interaction strategies for accessing and sharing HIVE data in Aotearoa-New Zealand. We found that there is a need for data governance of HIVE data. This involves identifying and appointing stewards and custodians of the relevant datasets such that the datasets can be maintained and available for further use beyond their initial purpose.

We also found a need for building and nurturing stronger partnerships to continue building trust between stakeholders for sharing data. Trust is an important factor for facilitating data sharing between agencies, and for people to share their data with hazards and impact monitoring crowdsourcing/citizen science projects.

Furthermore, integration challenges continue to interfere with the use of various sources of HIVE data for effective risk and impact assessments for IFWs and beyond. Systematic and standardised data collection approaches using GIS-based tools can support integration. Many templates for standardised data collection were found to exist in Aotearoa-New Zealand but the resulting data has not been systematically collected into one place for easier access and use. Depending on licensing and proprietary restrictions, it may be beneficial to aggregate these data into a central repository for continued use.

This research provides empirical evidence supporting the need for establishing roles and practices for governing HIVE data in Aotearoa-New Zealand. This is in support of both meeting the Sendai Framework priorities and implementing an IFW system for severe weather hazards in Aotearoa-New Zealand. Building partnerships remains key to improving data collection, access, and sharing practices for DRR. Further research can investigate how these partnerships can be built and strengthened.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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