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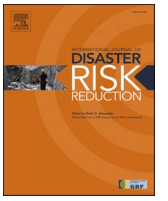

Infrastructure planning emergency levels of service for the Wellington region, Aotearoa New Zealand – A preliminary framework

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ABSTRACT

Elements of a potential emergency response to a major hazard event can be identified early in the response planning process. Having goals for emergency provision of services, particularly infrastructure, would provide clear planning goals and actions for emergency responders. Agreed goals would also help residents more fully understand the likely nature of the service provisions following a major hazard event, allowing them to plan for events and resulting infrastructure outages. This paper proposes a set of 'planning emergency levels of service' based in literature and developed by practitioners that could be used to understand post-event planning and actions, across the critical infrastructure sectors. The resulting framework contains proposed planning emergency levels of service for the energy, telecommunications, transport, and water sectors. With potential local adjustment, this framework may be more widely applicable for other high-income regions. Limitations of the framework include that it has been developed based on literature and emergency management professionals' opinions and requires more research to ascertain its operational applicability.

1. Introduction

Natural hazards have the potential to cause humanitarian impacts. In the past, earthquakes, tsunami, hurricanes and droughts have had devastating effects on communities. Although very different in nature, the outcomes of those hazard events on communities may have similar characteristics, such as loss of access to food supplies, loss of water supply and loss of power supply [1]. Whether in a low- or high-income context, and whatever the cause of the infrastructure outage, people immediately affected by a major hazard event have needs, both in the short-term response and over the following months during their pathway towards longer-term recovery [2]. While such events may happen in any part of the world, some locations are known to be vulnerable to specific hazards, such as hurricane-prone regions, or seismically active areas [3,4] such as Wellington, the capital of New Zealand.

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There are known vulnerabilities in the various critical infrastructure networks in the Wellington Region, which make them prone to damage and disruption following hazard events. These are across the energy, telecommunications, transport (and consequently food delivery) and water sectors. For example, following a rupture of the Wellington fault, reticulated water outages are anticipated to be between one and twelve months, and power outages between one week and six months [5–7].

If a hazard event were to occur, the residents of the region require access to the infrastructure services (if not the infrastructure networks), to continue to live in the area, or at least survive until they can move to safety. If residents' needs can be defined, the gap between needs and expected delivery of services by the infrastructure providers can then also be defined at 'suburb level' for key scenarios. The identification of any gaps will aid the lifeline utilities and emergency management sector to refine emergency planning for those people that will be affected by the potential impact event. Similarly, this information would be useful to the individuals (and communities) themselves, setting expectations of delivery and allowing detailed local emergency planning to take place.

In this paper we consider the specific case of the Wellington region, New Zealand, by combining international literature on post-disaster emergency levels of service with locally specific literature and emergency management initiatives. We anticipate that this approach will be useful in other vulnerable locations where the levels of service identified in this review could be adopted.

The term 'level of service' (LoS) is used in this paper because it is a commonly used term in infrastructure asset management practices, where 'infrastructure is described by asset condition, performance and other relevant outputs' [8]. For example, it may refer to the quality or reliability of power supplies, quantities, and quality of water to be provided to end-users or surface condition on roads. If described well, such descriptions should also be able to be understood by laypersons. Adding the words 'planning emergency' shows that this measure is specific to the LoS planned to be delivered during or after an emergency or major event.

2. Wellington region context

Wellington City is the capital of New Zealand. The greater Wellington region is made up of eight local council areas (Fig. 1). The hilly topography, the presence of active faults, liquefaction-potential soils and strong winds mean that the region is vulnerable to a range of hazards, including earthquake, tsunami and storm events [7] all of which can lead to potential infrastructure outages. Further, due to its topography there are limited transport routes into and out of the region, which leaves the region particularly vulnerable to the consequences of earthquakes. The population density is highest in the Porirua, Upper Hutt, Hutt City (Lower Hutt) and Wellington

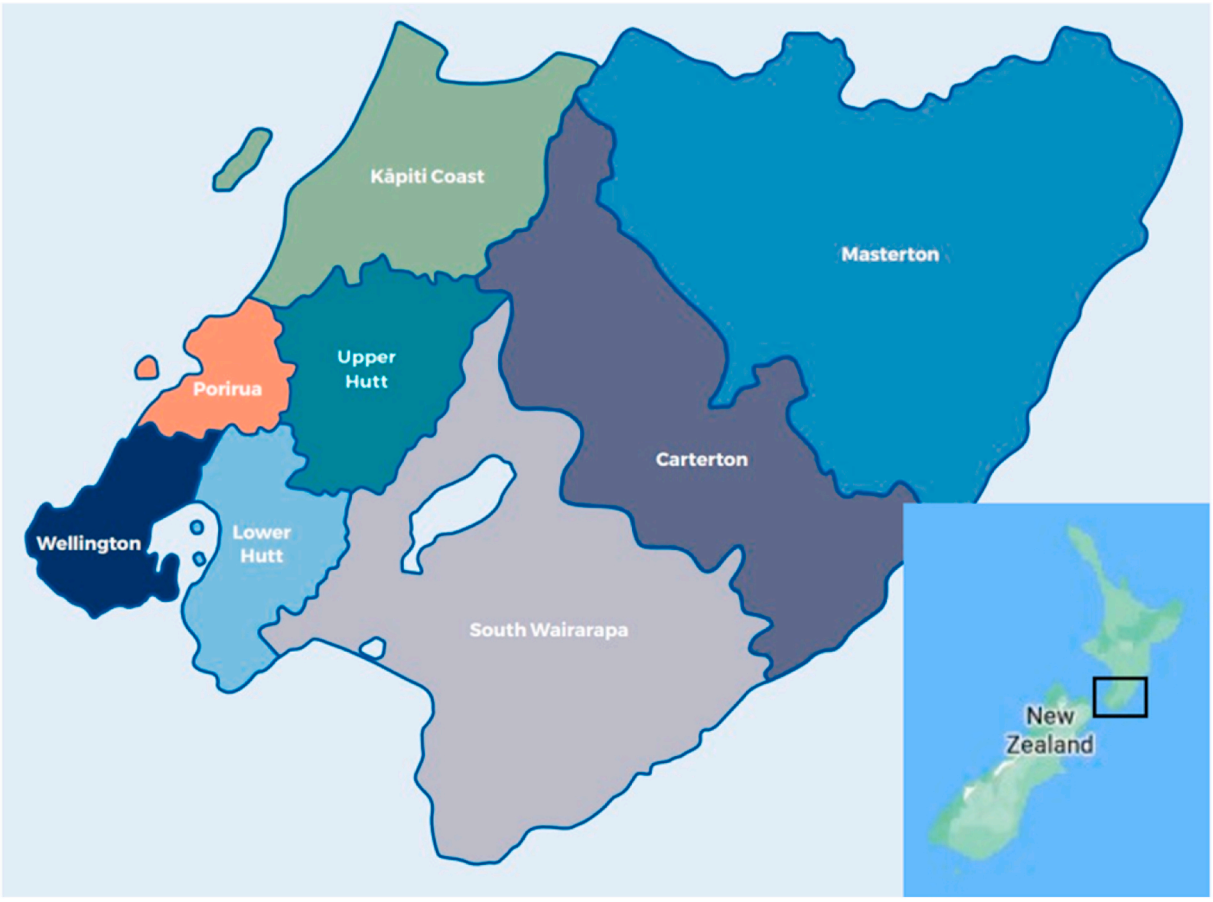

Fig. 1. Local councils comprising the greater Wellington region, New Zealand.

City areas, leading to those locations sometimes being referred to collectively as the 'Wellington metropolitan area'. While the Kapiti Coast also contains larger towns, parts of it, and the majority of the Wairarapa (covering Masterton, Carterton and South Wairarapa) are considered rural areas. This means that in the region, the densest infrastructure networks are in the metropolitan area, with either less dense networks, or private supply (i.e. for water) in the rural areas. This factor impacts the organisational make-up of the utility providers, for example Wellington Water serves the metropolitan area (and since 2021 the South Wairarapa). There are reticulated gas networks for the Kapiti Coast and Wellington metropolitan areas, but not in the Wairarapa. The main focus of this paper is on 'urban areas', and therefore is most focussed on the Kapiti Coast and metropolitan area issues, although it is likely that some of the concepts outlined in this paper could be translated to the Wairarapa (rural areas), which will be the subject of future work.

The climate in the region is temperate, however occasional high windspeeds through the Cook Strait (between the North and South Islands of New Zealand, which is located in the 'roaring forties'), leads to the nickname of Wellington as the 'windy city' [9]. This wind has impacted the design of the power supply network, which is relatively robust against high, but not extreme, winds, and has impacted the design of houses, buildings, and structures. Temperatures rarely drop below freezing, however the heating of dwellings is still needed, most normally carried out by electricity or gas-powered heating.

The emergency planning function for the region is carried out for local government by the Wellington Region Emergency Management Office (WREMO). The water networks for the Porirua, Upper Hutt, Hutt City, Wellington and South Wairarapa Councils are operated by Wellington Water, a Council Controlled Organisation. The remaining infrastructure networks are managed by a combination of central government (State Highways and rail), local government (local roads, other water networks) and private companies (two of the power lines companies, the gas reticulated networks and the telecommunications providers).

3. Methodology

3.1. Literature review methodology

The literature review was carried out using English language sources from academic databases using the Massey University library site, which searches Scopus, Web of Science, psychINFO, MedLine, and also from Google searches. The reference lists of relevant academic papers in turn led to papers on particular measurement frameworks, 'resilience' measurement studies and LoS (and similar) texts. The Google searches largely brought up references to specific infrastructure LoS, and related information including literature from UN agencies, governmental and non-governmental sources, and infrastructure providers. For both library and Google searches, the key words included searches for the following terms:

- Post-disaster goals, performance levels, availabilities
- Disaster standards
- 'emergency levels of service', 'recommendations', 'standards', 'performance goals' coupled with sector labels such as: electricity/energy, utility/utilities, transport, access and also: 'individuals', 'households', 'users' etc.

Searches were conducted with the above terms, both with, and without, AND/OR operators for searches.

In addition, searches were conducted on the use of frameworks for the definition of resilience at city and region levels using similar searches to those listed above, but including the labels: framework', 'definition' and 'adopted'.

As an addition to the above searches, the references and 'further reading' lists at the ends of chapters in the Sphere Handbook [2] brought forward a rich set of references that were relevant to this literature review. All references were captured and organised using EndNote.

3.2. Framework creation methodology

Regoniel [10] describes the four steps of how to create a conceptual framework as: choose [the] topic, do a literature review, isolate the important variables, and generate the conceptual framework. Here, guided by the results of the literature review, and using the action research methodology [11], the authors created the preliminary framework through a series of practitioner discussions in which the key variables (infrastructure sectors) were discussed individually. The framework (in Section 4.3) was built up through these discussions. These discussions were held between the Community Resilience and Recovery & Group Recovery Manager (WREMO), the Lifeline Utilities Co-ordinator (the lead author of this paper) and a WREMO Emergency Management Advisor. Between them, these people had a total of over 25 years of experience of working in emergency management in the Wellington region, covering community engagement, emergency planning, engagement with the lifeline utilities (critical infrastructure providers) and recovery planning. Two of the people had worked in developing country contexts, giving them an understanding of emergency or low-cost delivery, as relevant to the Sphere Handbook [2]. Discussions centred initially on the need for, and broad structure of, the framework, which led to the table format of the framework. As the literature review progressed, meetings then centred on individual cells of the framework. Where no obvious or available LoS were found in the literature, for example for power supply, the authors proposed new LoS. In most cases, the LoS presented in the preliminary framework have not been the subject of detailed research or deep investigation and are based on the opinions stated at the meetings, and consequently require further research. Generally, as will be seen in Section 4.2, the discussions balanced the 'ideal' (i.e. full delivery of services without disruption, or alternatively LoS identified in literature) against the modelled outages given in the WeLG Programme Business Case [6], which were considered a 'worst case' set of infrastructure outages that could impact the region. The aim of the discussions was to identify what the needs of individuals are, for a basic service, and use that as a goal (or, in this case, LoS) for delivery. There were no fixed questions or agendas, or formal means of analysis for these meetings, instead using the issues raised through the literature review to prompt discussion. The above meetings and work were carried out under a low-risk ethics notification via Massey University, New Zealand.

4. Wider issues regarding the setting of 'emergency LoS'

Section 4.1 of the results highlights initial context-setting information that was found in the literature review, and deemed to be important when developing LoS. These include wider issues, response versus recovery timeframes, the need for LoS and other existing frameworks. The next section 4.2 outlines how the preliminary framework and LoS were derived using a combination of the literature review and group discussions. Section 4.3 presents the overall framework in tabular format.

4.1. Wider issues regarding the setting of 'emergency LoS'

4.1.1. Human rights and response goals

Some aspects of emergency provision can be linked back to human rights: the United Nations Economic and Social Council [12] declared access to adequate food as a human right, and the UN General Assembly declared clean drinking water and sanitation a human right [13]. The Sphere Handbook [2]; p. 8), which is largely focussed on low cost and humanitarian relief situations, explores this aspect, and uses those human rights to help define standards for service provision. However, not all infrastructure services are identified as being related to human rights including, for example, the provision of a power supply (although power is required at an operational hospital, and healthcare is a human right), an issue which is explored further in the discussion section of this paper.

4.1.2. Moving from response to recovery

As Johnson and Olshansky [14] explain, while the first-flush of response to an event may take weeks to months, "physical recovery from disasters takes many years …". Haas, Kates, and Bowden [15] (cited in Johnson and Olshansky [14] provide a model that gives phases of recovery as 'emergency' (over the days following an event), 'restoration' (starting days after an event, and lasting up to 4 months), and 'reconstruction I and II' (lasting months to years). Using this scheme, the span of this paper predominantly covers Haas et al.'s emergency and restoration phases.

4.1.3. The need to set LoS, and setting them

The Sphere Handbook states that it is "a voluntary code for quality and accountability … It is not a 'how to' guide, but a description of what must be in place as a minimum for people to survive and recover from crisis with dignity." Further:

"Conforming to the Sphere standards does not mean implementing all key actions or meeting all key indicators of all standards. The degree to which an organisation can meet the standards will depend on a range of factors, some of which are beyond their control. Access to the affected population, or political or economic insecurity, may make achieving the standards impossible in some contexts." [2]; p. 8).

The above demonstrates why the Sphere Association considers that standards should be in place for a response, but also sets context for the delivery of services, acknowledging that the nature of a hazard event may make some services impossible to deliver. The Handbook also indicates that equity of delivery is also a goal – the delivery of services may not be to the stated LoS in some locations, and no delivery may be achievable at all in some other locations.

Bross el al [16] argue that apart from the Sphere Standards, very few other disaster-context water standards exist that could be used for high-income contexts, and what standards exist, tend to focus on the management of utilities and service activities rather than on the quantities or quality of the output. Their paper argues that without standards or goals, emergency planning frameworks cannot adequately define the outputs required. This argument could be widened to apply to other infrastructure sectors.

4.1.4. Measuring emergency performance of infrastructure – other frameworks

There are various frameworks for the assessment (or measurement) of resilience. Three of these are for measuring city-scale resilience using qualitative measures - the UNISDR (Disaster resilience scorecard for cities), Rockefeller Foundation (City Resilience Framework) and ISO37123. None of the above frameworks provide any scale or recommendation on what is, or is not, considered resilient, or any target level of provision of the measurements given in the frameworks. While the number calculated for each measure could be compared against other cities or regions, the question of 'so what?' is not addressed well. The National Institute of Standards and Technology (NIST) framework (and its predecessors for San Francisco, and the States of Oregon and Washington) for 'Community Resilience Planning Guide for Buildings and Infrastructure Systems' (for the USA) is a framework specifically designed to be used by communities to develop performance goals for post-event LoS [17–20]. This group of frameworks concentrate on, for example, the specifics of the functioning of an infrastructure network, providing a measure of aspects such as the 'design hazard performance' of the transmission and distribution (including substations) of electricity to 'Hospitals, Police and Fire Stations/Emergency Operations Centres'. Three frameworks (SPUR, Oregon State and Washington State) have stated emergency levels of service, with timeframes for the restoration of services, alongside estimates of when services will be restored with the infrastructure at the time of the writing of the respective reports. While these three documents all include stated goals for the restoration of services, these are generally infrastructure service 'input' goals such as "electricity: distribution: 60% restored" [20]; p. 19) or specific road-based, for example "Tier 1" State Highway bridges will be opened by 'day x' [21]; p. 143). These documents are incredibly valuable in setting expectations for both the infrastructure providers and the relevant communities on outage goals and likely performance levels.

While the above frameworks bring aspects to understanding planned post-event infrastructure performance, none of them provide stated LoS that would be meaningful to the end-users.

4.2. Deriving the preliminary framework and LoS

This section explains why particular LoS have been chosen for the preliminary framework from an analysis of the literature available for each sector (water, roading, food and LPG, fuel, power (electricity), telecommunications, broadcast, sanitation and

shelter).

It is intended that the framework be viewed holistically and not solely by sector. The interdependencies between the sectors is critical and is a key requirement in any detailed mitigation planning taken for any particular LoS. The delivery of some of these aspects depend on each other – for example food delivery and the transport of fuel to the hospital for its power supply will both depend on road access. Further, these LoS should not be viewed as being provided in isolation. It would be insufficient, for example, to provide for all emergencies LoS to a community except for the water needs, as without adequate water supply the community would still have to evacuate. Delivery of all critical services will allow for the progressive recovery of individuals and the community.

The preliminary framework uses the time periods for the incremental restoration of services as: 'the first week' (self-sufficient for seven days); 'the rest of the first month' (basic functionality); 'the second and third month' (moderate functionality) and 'beyond' (significant functionality). The first of these time periods was chosen as it matches current emergency preparedness messaging carried out by WREMO. The other time periods were chosen as they are easily understood and there is expected to be meaningful improvements of service delivery over these periods. The timeframe adopted here is simpler than those used in other regions; for instance, NIST, Oregon, San Francisco and Washington State have between nine and eleven timeframes [19–22]). The simplified timeframe used here was considered by practitioners to be appropriate for the region, and allows for the difficulties in predicting 'exact' timeframes for service provision.

This paper does not define how these LoS should be met, allowing for a range of delivery methods. For example, water could be provided by a wide range of means, including through piped networks, via tanker truck delivery, collected as rainwater from roofs or as bottled water. The means of delivery are for the utilities to plan for, and where they see that they cannot provide those LoS, to co-ordinate with emergency management organisations.

The authors have attempted to balance what is recommended/ideal on LoS from the literature against what is practical/achievable in the Wellington region. It would be pointless creating a set of LoS that will likely never have the potential of being achieved. Equally, it is recognised that very 'soft' goals with long timeframes would be of limited use to most stakeholders. There may be debate around whether the LoS are 'exactly' correct, however, they provide a starting point for discussion, and a greater understanding of the likely LoS that could be adopted once more research has been done.

4.2.1. Water

4.2.1.1. Literature – water. There is a comparative wealth of information on the needs of humans for a water supply, typified by Howard and Bartram [23]. Aimed at low-income and emergency environments, the World Health Organisation (WHO) and the Water, Engineering and Development Centre (WEDC) [24] suggest different stages of water needs - 5 L/person/day for 2 weeks to one month following the emergency intervention (response) with a maximum distance of 1 km between shelters and water points, increasing to 15+ litres/person/day by 3–6 months from the initial intervention. A key principle is to aim for incremental improvements over time. The WHO states that in relation to the distance between the water collection point and the shelter, at either a distance of 1000 m or a collection time of 30 min, the quantity of water collected is often below 5 L/person/day, however with 'optimal access' quantities of

Table 1
Summary of water emergency storage and restoration goals.

Location/context	Water storage recommendations and post-event restoration goals and definitions
International	
WHO [25]	'Basic': 20 L per person per day within 1 km of the dwelling
Sphere Handbook [2]	15 L per person per day within 500 m of the dwelling
USA	
State of Washington, USA [26].	1 gallon [of water] [approximately 3.8 L] per person and pet per day for drinking, cooking and hygiene needs for '2 weeks' should be stored as preparedness for an event
[18]	Emergency kits should contain 'two weeks supply of food, water and other necessary supplies'
[27]	Advise storing 'one gallon per person per day' for three days (for evacuation) and two weeks (for supply at home).
New Zealand	
New Zealand [28]	3 L per person per day for three days or more
Wellington Water [29]; p. 33) (For further details, see below.)	A goal of delivering 20 L of water, per person, per day, within 1 km of the dwelling, from 'day 8' after a major earthquake. ' … provide 80% of our customers, within 30 days of a reasonable seismic event, with at least 80% of their water needs (80-30-80 Strategy).'
[30]	'may be microbiologically unsafe' 'tankers or standpipes available within 500–1000 m of home or minimum reticulated supply of 20 l/person/day'
For Auckland, Watercare (the Auckland, New Zealand, water supply utility), Buxton, Wright, Daly, Timar, and Mieler [31]	Definition of four 'classes of water demand experience': • full water, • water restrictions are in place, • no reticulated water (or reduced pressure), and •water is available but not potable, i.e. requiring boiling or other treatment to make safe to drink.
Proposed for Christchurch, post-earthquake of 2011 [32]; p. 47)	Percentage of premises and critical facilities with water supply. For example: within 48 h, 90% of domestic premises and 95% of critical facilities receive service. Within 1 month, 90% of city receives water confirming to NZ Drinking Water Standards.

100 L/person/day can be collected [25]. Distances beyond this mean that people tend to collect less water, potentially less than minimum requirements.

The Sphere Handbook defines a standard for water supply being 15 L/person/day, within 500 m of the dwelling. The Handbook includes standards for water quality, collection time and queuing time, provides references relating to the standards within each category, and additional suggested reading on the subjects, providing good evidence for why those particular standards were selected [2].

For high-income regions exposed to hazards, available information on LoS for water is shown in Table 1: Summary of water emergency storage and restoration goals:

Wellington Water additionally outlines that 3 L water/person/day will cover drinking, cooking and hand-washing, while 20 L/person/day will cover other activities including dish washing, cleaning wastewater buckets and other functions [33]. Wellington Water [29]; p. 33) has the goal of delivering 20 L of water, per person, per day, within 1 km of the dwelling, from 'day 8' after a major earthquake, and for restoring services, aimed at resilience, 'to provide 80% of our customers, within 30 days of a reasonable seismic event, with at least 80% of their water needs (80-30-80 Strategy).' This strategy is based at the community-wide, or city-wide level, rather than at an individual or household level.

4.2.1.2. Proposed LoS – water. For water supply in the Wellington region, some key considerations must be taken into account. The nature of a major hazard event such as a large earthquake or tsunami means that there will be considerable damage to the existing infrastructure networks, including the water supply and road networks, in such an event. It will take time to repair the networks to even a basic level of service. There will effectively be very limited, or no, supplied water provision (by piped network, or via truck tankers or shops) to individuals within the first seven days of a major event [34]. In preparation for such an event, WREMO advises that all households store water for emergency use [35] and it markets 200 L emergency water tanks for this purpose [36]. We assume for this framework that no water will be delivered to individuals within the first seven days of an event.

Wellington Water's plan for water provision from 'day 8' following a major event is covered in their 'Community Infrastructure Resilience' project [37]. An emergency water supply network intended to deliver 20 L of water per person per day, within 1 km of the dwelling, has been developed, using emergency water sources such as bores and streams, and a supply network of transport and distribution bladders. This is also in line with the 'basic standard' detailed by the WHO [25].

The practitioners decided that although the Wellington Water initiative only covers the Wellington metropolitan area, this level of service could also be appropriate for the greater Wellington region, including the Kapiti Coast and Wairarapa (all areas shown in Fig. 1), so is included in the framework (Section 4.3). This is the only sector in which the expert panel needed to apply only minimal judgement, or balance 'ideal' versus 'likely' delivery, due to the excellent information and LoS provided by the WHO and in the Sphere Handbook. The 80-30-80 strategy (Table 1) [29] is also adopted as the framework level of service for days 31 to day 90 following an event. The LoS taken for the water sector are therefore as shown in Section 4.3. Further work is required to understand the different characteristics of water supply in the urban vs rural areas. While the emergency plan outlined for the Wellington metropolitan area is a viable plan (where the LoS is for water to be available within 1 km), distances for delivery will be greater in rural areas. It is also likely

Table 2
Reasonable walking or cycling distances.

Reference	Study context and location	Reasonable walking or cycling distances
Dora and Phillips [49]; p. 32) (WHO)	Transportation policy for European countries	The WHO advocates for policies that promote a shift to walking and cycling for "many trips shorter than 5 km"
Sphere Association [2]; p. 205)	Low cost and emergency response environments	' … distance from dwellings to final distribution points or markets (in case of vouchers or cash): Target <5 km'
Watson, Carlson, Humbert-Rico, Carroll, and Fulton [50]; p. S59)	Physical activity and health study, US adults.	'47% [of adults] thought walking up to 1 mile was reasonable' (p. S59) '45% of adults thought it would be reasonable to walk more than 1 mile [1.5 km].'
Badland, Schofield, and Schluter [51]	Physical activity and health study, commuters in Auckland, New Zealand.	Over 60% of people considered it acceptable to commute between 2 and 4.9 km by transport-related physical activity (walking or cycling)
Yang and Diez-Roux [52]; p. 12)	Epidemiology (health), study in the USA.	'The upper tail-ends of the distributions [of walking distances] can also provide a sense of the walking distance and duration that are actually achievable under certain circumstances.' Mean cumulative distance per day of those that walked was 2.3 km.
Larsen, El-Geneidy, and Yasmin [53]	Urban planning, Montreal, Canada.	The median distance for walking for shopping was 581 m and for cycling was 1529 m. Around 1.7% of walking trips were of 2 km distance or more, and less than 1% of 3 km distance or more. Around 8% of cycling trips were of more than 2 km distance and less than 6% of more than 3 km distance.
Chinese national standard GB 50413–2007 (quoted in Xu, Yin, Chen, An, and Nie [54]	Disaster planning, China	Distance to a temporary emergency shelter, may be up to 0.5 km. Distance to a fixed emergency shelter, may be up to 2 km.
Allmagian [55]; p. 103)	New Zealand tramping (walking) guide	'As a guideline, an average group will walk: 4–5 km per hour on a smooth wide track.'
[56]	Transport survey, 2015–18, New Zealand	'31% of people cycled in the past year' '16 min – the average cycling trip leg' '1 km – the average walking trip leg distance'

that a proportion of dwellings in rural areas may be on individual water supplies, in which case a LoS for centralised water supply will be less relevant. This is an area where further work is required to understand what LoS may be appropriate for water supply in rural areas.

4.2.2. Road access

4.2.2.1. Literature – road access. There is a wide range of literature on road access following an emergency, particularly on the analysis of road networks for their resilience or adaptability. Konstantinidou, Kepaptsoglou, and Karlaftis [38] reviewed a range of studies on pre- and post-disaster transport network availability. These were sorted into two categories – those that modelled post-disaster transport network performance and those that considered post-disaster decision-making for the network. One reviewed study included metrics for an "emergency facility-weighted' measure which uses formulae for calculating outages, but does not recommend actual outage timeframes or LoS [39]. The literature is heavily weighted towards modelling of the performance of road networks following disruption to the network to assist with decision-making. This is highly relevant to contexts where there are road networks that have multiple alternative routes, where traffic can be diverted, but less relevant to Wellington, where few viable alternative routes exist, and where single hazard events such as a large earthquake can impact many roads simultaneously.

The National Cooperative Highway Research Programme Transportation Research Board of the National Academies produced 'A guide to regional transportation planning for disasters, emergencies and significant events' [40]. This document outlines 'how' to plan for transport outages, describing eight principles for emergency planning: a plan must be comprehensive, cooperative, information, coordinated, inclusive, exercised, flexible and continuous. This document provides a good basis for emergency planning but does not include goal setting.

In New Zealand [41], does supply an indication of LoS for roads, from nationally-important high volume roads to low volume access roads. For example, for regional roads, they provide statements such as: "Route is always available except during major-extreme weather or emergency events and viable alternatives nearly always exist." No specific timespans are indicated.

For the performance of individual structures such as bridges, both the California Department of Transportation [42] and Waka Kotahi NZTA state the return period design event that structures on 'important' or 'recovery' roads (Caltrans) or any State Highway (NZTA) should be designed for. While this provides guidance on the intended performance of structures to hazard events, these do not give network-level (i.e. road) performance levels.

In summary, there are few stated standards for the availability of road access following a major hazard event that are measurable. Those which do exist are either dependent on the road network being permanently available (ambulance access [43]) or do not give specific figures for access, focussing instead on broader statements of reliability and/or availability. This is probably a result of uncertainty of exactly how a road, its related infrastructure (such as retaining walls or unretained slopes) or closely located structures such as buildings, will perform in a hazard event, which can make predictions of availability and the setting of standards difficult.

Where road access is temporarily not available, many trips may be taken by individuals by active transport (walking and cycling), navigating around specific locations of road damage. There is a relative wealth of literature, particularly in urban planning and public health sectors, on feasible walking and cycling distances for individuals. A trip distance considered walkable or cyclable will differ between individuals [44–47]. Further, there are differences in what will be acceptable to populations in different countries, for reasons that may include culture, availability of walking routes and cycling paths and proximity to facilities. A direct comparison of walking practices in the USA and Germany demonstrated differing active transport practices between people in those countries, where there was a greater proportion of trips carried out by active transport in Germany compared to in the USA [48]. Despite such differences, understanding the public's walking habits and preferences can help understand the practicalities of active transport as an alternative to car travel (Table 2).

While most of the above studies and sources are from outside New Zealand, they do provide a basis for understanding the relative distances people are prepared to walk and cycle daily, or specifically to walk or cycle on shopping trips. As can be seen, the existing standards (Sphere Association, WHO and the Chinese national standard) show that, internationally, a 5 km distance to 'market or [food] distribution point' is considered appropriate, or 2 km to a fixed emergency shelter. Studies from both within and outside New Zealand demonstrate that very few members of the community are likely to be willing to travel 5 km by active transport (walking or cycling), however willingness increases as distance decreases. In New Zealand, a 2021 government advertising campaign to reduce greenhouse gas emissions encouraged the public to undertake household trips by 'climate-friendly modes of transport such as biking, scooting and walking when making trips under 2 km' [57]. Genless do not make a distinction in this advice regarding active transport on flat ground versus on hills. Wellington has a hilly topography.

4.2.2.2. Proposed LoS – road access. While many services could be delivered by other means, in the Wellington region the availability of the road network is a key factor for the delivery of many needs, including the delivery of food to supermarkets, the collection of water (as planned for, in an emergency event) and for access to medical care.

The relative lack in literature of stated emergency, or post-disaster, LoS for transport networks makes it harder to define LoS that have specific references to known standards or guidelines. For the creation of this preliminary framework, the practitioners decided that aspects that were considered key for emergency response and recovery, as relevant to individuals, were for food delivery, water, healthcare and for access to Community Emergency Hubs (locations of community gathering/response following emergencies). For this, the recommendations for 'the first week' and 'the rest of the first month' at a local level were defined by access between the house and medical centres and Community Emergency Hubs. Additionally, a priority route mapping in the Wellington Region Earthquake Plan (WREP) [58] which defines emergency response transport routes required to connect key locations (such as the hospitals and airports) and provide a spine of access to and within the region was available. Within this priority routes mapping, the 2nd, 3rd and 4th priority routes include coverage of facilities such as supermarkets. A priority route does not, however, guarantee that any particular

route will be open by any particular day following an event. Further, the locations of supermarkets, while tending to be covered by the priority routes, are not uniformly located on any particular level of priority route. Rather than be in the detail of defining which facilities or functions are catered for by the access network, instead the framework identifies assumptions on regaining access for priority routes. The balance for the expert panel was between knowing the reality of likely road outages against the need for access to, for example, food and health care following an event. The panel decided that the framework should describe 'reality' for most areas, by highlighting that road access will be unavailable in areas, therefore highlighting that access to, for example, the hospital will be impacted in the days following an event. The LoS taken for the road access are shown in Section 4.3.

4.2.3. Fast moving consumer goods (FMCGs) (for food)

4.2.3.1. Literature for FMCGs. In New Zealand, the FMCG sector, which includes supermarkets and corner shops (the food distribution system) is not considered a infrastructure provider, however it is often considered alongside the infrastructure providers for emergency response planning. This is because in New Zealand the distribution of FMCG stock is mainly carried out on the road network, thus the functioning of the FMCG networks is heavily dependent on road availability. Other key dependencies include electricity for refrigeration and telecommunications networks for payment.

Minimum food requirements for humans are well researched and understood and are also covered within the Sphere Handbook [2]. Although the Handbook gives nutrition requirements of '2100 kCal per person per day with 10–12% of total energy provided by protein and 17% provided by fat', they note that it is not practical to measure actual energy and nutrient intake during initial assessments, so use proxy indicators. For this reason, the Handbook instead focuses on the measurement of percentage rates of malnutrition, and other factors. Sphere also provides guidance on the locations of provision points, noting that distribution and delivery points should be located at sites accessible, safe and most convenient for recipients, and recommend the distance from dwellings to final distribution points or markets be less than 5 km.

The UNHCR, UNICEF, WFP and WHO document "Food and Nutrition Needs in Emergencies" gives specific levels of nutrition, including example rations of essentials such as cereals, pulses, oil, meat, sugar etc. along with recommended daily intakes of various vitamins [12,59,60]; & [25,60]. This paper will not investigate further such nutrition specifics, as they have been heavily researched in other contexts, and in any case are unlikely to be a useful measurement in the Wellington region, post-event due to the availability of pre-existing supermarkets (or equivalent) in the region, from which food can be collected, once resupplied. In the Wellington region, rather than addressing nutrition needs, a simpler and probably more effective means of measurement for food availability will be 'distance to supermarket or food distribution point'. For this, Section 4.2.2 (above) provides an overview of willingness to use active transport (walking and cycling) to access food supplies, including in an emergency.

4.2.3.2. Proposed LoS for FMCGs. For the preliminary framework, the distance between dwellings and a functioning supermarket is adopted as an appropriate and readily understood measure of food availability. While the Sphere Handbook recommends that the distance between dwellings and final distribution points or markets be less than 5 km, for urban Wellington practitioners considered this distance to be too great as in practice most of urban Wellington is within 2 km of a supermarket. Thus, the framework adopts a 2 km maximum distance between dwelling and supermarket as the target LoS for timeframes beyond the end of the first week through the second and third months (Section 4.3). For the first week after a major event, the planning assumption, communicated by WREMO to the public, is that residents will have to rely on their stored food reserves, in parallel to the advice for storing water [35]. This is a set of LoS in which the expert panel had to find a balance between the 'ideal' and the practical. Any proposed LoS for walking distances will not be achievable for some members of the community, particularly those who are old, young or have mobility impairments. This issue is addressed in Section 4.4, but the key aspect is to note that assistance will be required from others to support those unable to move up to 2 km to access food supplies. A further consideration is that there is a supermarket within 2 km of most (over 90%) dwellings in the Wellington metropolitan area. This was considered by the panel to be an acceptable balance for the LoS provided in the framework.

While food availability is key, the ability to cook and to boil water is also a key consideration. In the Wellington region (as in much of New Zealand) there is a popular culture of summer barbeques. Many households have barbeque facilities, normally used with 9 kg liquid petroleum gas (LPG) bottles. These bottles are widely sold, as replacements/refills at supermarkets, fuel stations and other stores. For this reason, and with the obvious connection with food supply, the practitioners decided that the LoS for LPG be similar as for food in terms of distance. The LoS taken for the food sector, and for LPG, are therefore as shown in Section 4.3.

4.2.4. Fuel

4.2.4.1. Literature for fuel. In most contexts, including the Wellington region, once delivered by ship to the tank farms, access to fuel is heavily dependent on road access, and on vehicles (tankers) to distribute fuel to service stations. This means that any emergency standard for fuel delivery could, in part, be related to road access. An alternative to an emergency level of service for access to fuel could be a LoS for pre-event onsite storage of fuel for use by individuals or organisations in an emergency event. While this would be prudent, no specific LoS for access to fuel in an emergency were found in the literature. The literature that was found, focussed on the means of storage of fuel, generally for safety and environmental purposes, for example the Worksafe (New Zealand central government agency) [61,62] website outlining safe storage, summarising fuel storage legislation in New Zealand.

4.2.4.2. Proposed LoS for fuel. Following a major event, road access is likely to be unavailable for 'days to weeks' in parts of the region [6]. The restoration of the fuel supply chain will require a functioning port facility and fuel storage depots, road access, power supply to the service station and, for electronic payments a functioning telecommunications network. Therefore, the LoS for fuel availability in the framework focusses on rationing existing stored fuel until the fuel supply chain is fully functioning. The LoS is that existing fuel stored in tanks at service stations be rationed to critical customers such as emergency services until the end of the first month. For the

second and third months, the LoS goal is that priority service stations across the region are functioning (Section 4.3). Priority service stations are listed within Wellington Region emergency response plans; they are not a guarantee of fuel availability but provide an understanding of which service stations will first be supported for restoration of services by the emergency response partners. The expert panel considered that balance was created in the LoS by prioritising critical functions in response and recovery.

4.2.5. Power (electricity)

4.2.5.1. Literature for power. Kinn and Abbott [63]; who investigated the role that the provision of electricity held in resilience literature, found that, in their search of 4127 studies on resilience and disaster cases, only 3.9% had key words connected to electricity. This was mirrored in this literature review where there was comparatively little literature found on the resilience of power supply or power requirements in disaster response compared to other infrastructure sectors. The above paper also outlined the importance of a power supply to keep critical facilities such as hospitals functioning. In a similar vein, May [64] notes that in Puerto Rico, following Hurricane Maria, around two months after the impact of the hurricane ' … recovery efforts focussed on restoring power to critical institutions such as hospitals, fire stations, and water treatment plants, and that more than 50% of the island's 3.4 million residents were still without power'. The infrastructure effort in that case appeared to be on assisting priority sites to function.

Several examples were found that quantified the impacts of power outages on critical facilities. Laher et al. [65] note that 'for every day with a power outage lasting more than 2 h, hospital mortality has been estimated to increase by 43%'. They note that various medications and vaccines need to be stored within specific temperature ranges, an issue that will be particularly relevant to hospitals and pharmacies. These authors, and [66]. [65]; make recommendations for the provision and maintenance of alternative power sources such as generators, with adequate fuel supplies available, or alternative energy sources such as wind or solar.

With respect to continuity of power supply and food safety, Kosa, Cates, Karns, Godwin, and Coppings [67] reported that two days after a power outage in 2003 in New York, there was a statistically significant increase in patient visits for diarrheal disease to medical facilities and recommended that public health educators and educators tailor information on emergency preparedness to maintaining food safety during power outages. The Office of Personnel Management [68] recommends that during a power outage, refrigerator and freezer doors be kept closed as much as possible.

None of the above literature gave measurable standards for the post-disaster provision of power, nor does the Sphere Handbook [2] provide standards for power supply.

4.2.5.2. Proposed LoS for power. Following an earthquake cause by rupture of the Wellington fault, there is unlikely to be a networked power supply available for up to six months within the Wellington region [6]. The preliminary framework focusses only on emergency response provision, noting that power will be required for priority sites such as hospitals and police stations until the end of the first month. The framework is not specific on the means of supply of electricity to those facilities, meaning that if they are fitted with generators and can be supplied fuel, or supplied from other alternative sources, they could be powered without connection to the network.

In addition to powering priority facilities, the framework also includes the recommendation that individuals be able to power up telecommunications devices, such as mobile phones, at facilities such as community emergency hubs (the locations in which residents are encouraged to gather at for a community-based response). This power supply is noted in the framework to be 'within daylight hours' to reinforce that such facilities may only be powered by solar panels, although actual delivery of power may be carried out by any method. This aspect is necessarily interdependent with the capacity of the telecommunications network during the emergency, covered in the next section. The expert panel judged that prioritising power for essential functions and for charging telecommunications devices provided a balanced planning emergency LoS.

4.2.6. Telecommunications and broadcasting

4.2.6.1. Literature for telecommunications and broadcasting. Key information on resilience (including response and recovery) aspects of the telecommunications and broadcast sectors is provided by the International Telecommunications Union (ITU), which is a United Nations specialised agency for information and communication technologies. As an aggregation of key information, the Technical Report on Telecommunications and Disaster Mitigation, ITU-T Focus Group on Disaster Relief Systems, Network Resilience and Recovery [69] and the Broadcasting for public warning, disaster mitigation and relief [70] provide excellent resources on the provision of emergency telecommunications and broadcast services. The ITU-T [69] report notes that the loss of power affecting telecommunications services has been a significant factor in some disasters. Having a secure networked power supply, or access to alternatives such as generators, was highlighted as a key consideration for continued operations. The above report on telecommunications focuses on case studies gathered from the past decades when there was a greater use of landline (fixed) telephones. The greater reliance on cell phones in the 21st century creates different issues for telecommunications services provision.

The International Telecommunication Union [69] report also notes that to reduce telecommunications network congestion on calls (in the initial flush of response), various measures can be taken including "reassigning network resources to telephony" to allow people to call each other and "reducing call quality". This would mean prioritising telephone calls over data (i.e. internet) services. Further, priority can be given to the 'first responders and for emergency calls' (section 6.6.2.1). Again, this supports the concept of giving priority to some key facilities in a response such as those that provide emergency services.

The above report also notes two key aspects: that disaster information services should be available for all sectors of society, including the vulnerable (noted as deaf, blind, illiterate, old, young, visitors, international visitors and roamers), and also that while buried infrastructure is vulnerable to damage in a hazard event, radiocommunications are not susceptible to such damage. Therefore, above-ground networks will provide greater resilience to some hazards. Taking these issues together, the provision of broadcast services (such as VHF radio) can provide information to many people, including most sectors of society, in an emergency. Separately, the Communications Security, Reliability and Interoperability Council, which is an advisory committee that is part of the Federal Communications Commission, an independent US government agency published a report 'Working Group 2 B MSRC Best Practice Update', which includes a 'Local Radio Station Model Disaster Recovery Plan & Incident response manual'. This includes the statement that 'keeping all aural and data services on the air is most desirable, ensuring that the aural services remain on the air to serve the community is an absolute necessity' [71]; p. 11). This aligns with the ITU statements on the reliability of above-ground services, with the implication that the broadcast of VHF radio services should be of the highest priority. Broadcast can be a key means of disseminating information to a wider community.

4.2.6.2. Proposed LoS for telecommunications and broadcasting. While no standards were found in the literature review for the emergency performance of telecommunications networks, the ITU provides guidance on emergency telecommunications and broadcast strategies and actions. One aspect to be aware of, however, is that within the first two phases of the framework (self-sufficiency and basic functionality, covering the first month after the event) the preliminary framework contains LoS for power (electricity) to priority sites only. This means that there would be no networked provision of electricity to the household level. The lack of power supply to the household would impact the use of telephones, televisions and internet devices at dwellings. The practitioners therefore decided that framework should focus on radio station functionality (as many households own radios that can be used on battery power) and on hand-held devices that can be used at community hubs or other key locations for the period of the first three months.

The telecommunications and broadcast sectors are complex in their nature, with technologies evolving quickly, and (in New Zealand) a relatively complex telecommunications network provided by various owners/operators that provide a range of interdependent services. For this reason, the preliminary framework for telecommunications could have been relatively complex in terms of the kinds of device that were recommended for use. Instead, the practitioners decided that the 'starting point' LoS focus on the intended outcomes of the telecommunications use. In a hierarchy, the following outcomes were targeted: for the self-sufficiency phase, the ability to send and receive text messages, as this allows information to be shared, but causes less congestion issues on telecommunications networks [69]. For the basic functionality phase, the ability to have some level of use of mobile data was chosen as a level of service, as this allows individuals to use social media to communicate with their family and friends. For the moderate functionality phase, the ability to use voice call systems was recommended as an 'end point' for a functioning telecommunications system in an emergency.

In addition, many critical organisations such as central government agencies, emergency services and utilities own satellite phones (telephones that connect to telecommunications networks directly via satellites), which do not require a terrestrial telecommunications network, and can be used on battery power. For this reason, the 'first week' self-sufficiency phase acknowledges the use of such phones. These are unlikely to be a solution for the majority of private residents, due to their high cost of purchase and operation.

Regarding broadcast recommendations, as above, the availability of power supply at the household level means that radio services such as FM radio would provide the best means of broadcasting public information, if radios are powered by batteries. The availability of television services is therefore recommended for the 'significant functionality' phase of recovery. The expert panel considered that the provision of FM radio (for broadcast information) and the availability of basic telecommunications functions was a fair balance between the desirable (functioning TV and phone call capability) and the likely reality of modelled outages. The LoS taken for the telecommunications and broadcast sector are as shown in Section 4.3.

4.2.7. Sanitation

4.2.7.1. Literature for sanitation. As for the water sector, the Sphere Handbook [2] provides well-researched and referenced guidance and standards for sanitation provision. The standards include the statement (p92):

'WASH [i.e. water, sanitation and hygiene] requires particular considerations in urban areas. Community engagement can be harder in urban areas, where the population density is higher and at-risk groups are less visible … Diverse ownership of assets (households in rural areas, public–private mix in urban areas) affects the choice of response options and methods of delivery.'

The implication of the above section is that sanitation provision should suit the context for the end-users and that potentially more than one emergency sanitation model could be appropriate in each setting, based on location, the type of dwelling (detached houses with gardens vs high-rise apartments) and the ultimate end-users of the solution(s), covering those from a variety of cultural backgrounds, and covering a range of end-user requirements and capabilities.

The [72,73] provide guidance on a range of potential emergency sanitation solutions during times of wastewater system outages. Not all the solutions will be viable in all settings. For instance, chemical toilets require collection and disposal of the waste, which in turn require a functioning road network and wastewater treatment plant. Other solutions include bucket latrines, trench latrines and communal or family latrines.

For New Zealand, the public advice on the 'Get ready, get thru' website [74] includes the following statement on making an emergency toilet: "Use watertight containers such as a rubbish bin or bucket, with a snug-fitting cover." The use of watertight containers is recommended, presumably for use within the house, with the resulting waste being disposed of outside the home.

Following the Canterbury sequence of earthquakes commencing in 2010, discussions were held at Christchurch City Council on LoS for water and wastewater infrastructure. These discussions led to suggestions on how a level of service could be defined. An example

level of service was that within 48 h of an event, 85% of domestic premises should have a wastewater connection, and that within 2 weeks of an event 80% of effluent should reach the treatment plant. As of 2021, there is no record in the literature of the above LoS being adopted by the council.

While other studies are available, these tend to be applicable to low-income regions [75,76]. This means that evidence-based advice for New Zealand is less available, and no standards are given regarding the delivery of services.

In addition to the provision of a means of safe disposal of excreta, which is one aspect of sanitation, water is required for hand-washing [77]. Consideration of water provision is included in the water section, above.

4.2.7.2. Proposed LoS for sanitation. In a large earthquake, the wastewater networks will suffer high levels of damage, particularly in areas with a high liquefaction hazard and areas of slope instability, and as a result of co-seismic subsidence and horizontal movements. Therefore, the disruption to networked wastewater services, in some areas, will be for a matter of months or years [6]. For this reason, the framework focusses on alternative means of the disposal of sanitation waste.

While a good deal of research, from a variety of contexts and understandings, exists for some infrastructure sectors, the provision of emergency sanitation in a developed urban context is less well understood (Smith, M. Water, Environment and Development Centre, UK, personal communication, July 11, 2019). For the Wellington region, two references provide context on the risk of wastewater system failure [78] and challenges and opportunities to finding an emergency sanitation solution for the region [79]; In press). This appears to be an area ripe for further research. The Wellington Region Emergency Management Office, Wellington Water and the Wellington Region Public Health organisation collaborated on a project on emergency sanitation, with self-sufficiency up to 'day seven', then options for basic sanitation functionality [80]; Under review). The solutions recommended in that plan are relatively basic, including the use of two buckets for emergency sanitation, one bucket for 'wee' (urine), one for 'poo' (faeces) but allow for a variety of potential solutions at the household level and are adopted in the preliminary framework (Section 4.3). This LoS acknowledges that, while the desired LoS may be higher, the most realistic scenario, following a major event, is that households will have to make their own sanitation arrangements for a period following a major event. This LoS is therefore in line with the basic levels outlined in the literature, which will not be familiar to many in the community in the high-income context of the Wellington region.

4.2.8. Shelter

4.2.8.1. Literature for shelter. 'Shelter', or housing, is not normally considered 'infrastructure', but is part of the wider 'built environment'. It is a key factor for liveability (including survival, safety and security) for individuals following a hazard event. Although it does not strictly sit within a literature review for infrastructure providers, it was considered sufficiently critical to be included in this review.

For shelter standards, again the Sphere Handbook provides guidance, including some post-crisis settlement scenarios for both non-displaced and displaced populations and may be considered a source of best practice. [2]; p. 243). These scenarios include owner-occupied accommodation or land, rental and hosted arrangements etc.

4.2.8.2. Proposed LoS for shelter. The level of service used in the preliminary framework combines the wording used in the Sphere Handbook [2] with advice given by WREMO for emergency preparedness in the Wellington region [35]. Acknowledging that in post-event Wellington many houses and apartments may be uninhabitable in a major emergency [81], the preliminary framework is relatively open regarding the possible accommodation possibilities.

The overall preliminary framework for planning emergency LoS for the Wellington region is presented in Section 4.3, followed by a discussion of assumptions and caveats.

4.3. The overall framework

The overall framework is presented below as a compilation of the previously discussed individual preliminary LoS. As demonstrated in the infrastructure-specific parts of Section 4.2, the framework is intended to be a balance between the desired LoS and what is considered practical in the Wellington region following a major event. The holistic framework is:

Assumptions/caveats:

- Welfare support will be required for the more vulnerable – this will be achieved by support from family and friends, by the spontaneous community response within the suburb using existing assets available, targeted support to communities by the official response and/or NGOs and/or through official welfare support, where and when available.
- These recommendations may not be achievable and are only presented for planning purposes. Actual hazard events will define what is, and what is not, achievable 'on the day'.
- These recommendations are developed by practitioners, with the knowledge of the likely potential response capabilities in the Wellington region. They are not expected to be used in other contexts/locations (for which other, separate, recommendations could be developed.)
- The proposed LoS assume an able-bodied person is able to access these services independently. The more vulnerable will need to be assisted by others in the community (see also footnote 1 in the framework).
- 'End-user experience may vary' throughout - delivery is dependent on location and circumstance at time of the emergency.

Table 3
Wellington region - planning emergency levels of service[a] - PRELIMINARY FRAMEWORK.

Sector	The first week: self-sufficient for seven days	For the rest of the first month: basic functionality	For the second and third months: moderate functionality	Beyond: significant functionality
Water	Minimum of 3 L per person per day[b], but recommended 20 L per person per day, as stored at homes by individuals	15–20 L of water per person per day[c] within 1 km of the house	80% of supply of potable water to 80% of customers[d]	At least 80% of individuals receive at least 80% of 'BAU' delivery
Roading	Limited road use – only priority 1 routes[e] are open to emergency vehicles. Walking access to local medical centres and to Community Emergency Hubs is available.	Priority 1 routes are open and managed[f], priority 2 roads are open to emergency vehicles. Road access is available between dwellings and local medical centres and Community Emergency Hubs and between water stations and distribution points.	Priority 1 and 2 routes open and managed, and priority 3 and 4 routes open for emergency vehicles only.	At least 80% of individuals receive at least 80% of 'BAU' delivery
Food and LPG (for cooking)	As stored in individual homes, provided by FMCG suppliers who are still operating, or emergency food supply brought in with priority to vulnerable people	Access to a supplied supermarket or distribution pointg[g] within 2 km[h] following an event for urban areas	Access to a supplied supermarket or distribution point within 2 km in urban areas	At least 80% of individuals receive at least 80% of 'BAU' delivery
Fuel	Strict rationing to priority list of users (e.g. emergency services) using fuel storage in place at time of emergency	Strict rationing to priority list of users (e.g. emergency services) using fuel storage in place at time of emergency and any immediate re-supply	Priority service stations are operating	At least 80% of individuals receive at least 80% of 'BAU' delivery
Power (electricity)	Households use from local sources and response priority sites use own pre-arranged power supply for essential functions.	Households use from local sources and response priority sites use own pre-arranged power supply for essential functions[i]. Ability to charge telecommunications devices (such as phones and tablets) at a location within a local area such as at a local Community Emergency Hub.	Power to response priority sites and key infrastructure sites[j]. Ability to charge phones and tablets at a location within a local area such as a local Community Emergency Hub.	At least 80% of individuals receive at least 80% of 'BAU' delivery
Telecomm-unications	Ability to send and receive texts (albeit with potential delays). Satphone usage where phones are charged.	Access mobile data for minimal functionality at defined locations such as at Community Emergency Hubs.	Access mobile data for almost normal data capability. Priority users have full service.	At least 80% of individuals receive at least 80% of 'BAU' delivery
Broadcast	FM radio – Priority Stations[k]: fully operational[l]	Fully functional for priority radio stations, no TV	Fully functional for priority radio stations, no TV	At least 80% of individuals receive at least 80% of 'BAU' delivery
Sanitation	Self-sufficiency by the community for sanitation needs (long-drops, two buckets or similar (no council service)).	Service, according to the 'two buckets' plan.[m]	Service, according to the 'two buckets' plan.	At least 80% of individuals receive at least 80% of 'BAU' delivery
Shelter	Shelter within own property or with immediate support network or at mass temporary accommodation sites.[n]			

[a] These standards do not apply in 'red zones' or cordoned areas where people are assumed not to be sheltering.
[b] Taken from Sphere Handbook, section 2.1, page 107: https://spherestandards.org/handbook/editions/.
[c] Taken from World Health Organisation: https://www.who.int/water_sanitation_health/emergencies/qa/emergencies_qa5/en/(downloaded May 3, 2019) (20 L), from Sphere Handbook, section 2.1, page 107: https://spherestandards.org/handbook/editions/(15 L) and from Wellington Water's '80-30-80' strategy (20 L).
[d] Taken from Wellington Water's '80-30-80' strategy.
[e] See Wellington Region Earthquake Plan (WREP) of December 2018 for WREMO for priority routes (Annex F).
[f] Restrictions may be in place for non-emergency vehicles (to manage safety issues).
[g] Distribution points are listed in the Wellington Region Earthquake Plan (WREP) of December 2018 from WREMO. See Appendix G1.
[h] The Sphere Handbook (item 6.3) has a target of less than 5 km. https://spherestandards.org/handbook/editions/.
[i] For a list of priority sites, see WeLG/WREMO/WELA 'lifelines response priorities: February 8, 2019'.
[j] As included in the WeLG/WREMO/WELA Key Utility Sites document of 2016.
[k] See https://getthru.govt.nz/radio-stations-to-listen-to for a list of the priority radio stations.
[l] See http://transition.fcc.gov/pshs/docs/csric/WG2B-MSRC-Best-Practice-Update-Final-Report.pdf section titled 'Vulnerability Assessment Guidelines'.
[m] See Mowll et al. [80].
[n] See https://spherestandards.org/handbook/editions/for additional information/direction. Assumes staying within own home or property.

4.4. Assumptions, caveats and limitations

4.4.1. Key assumptions and caveats

A key consideration covered by the Sphere Handbook is the provision of services to those less able to provide for themselves such as the very young, the elderly or disabled. The Handbook [2]; pp. 10–12) notes that "individuals and groups within a population have different capacities, needs and vulnerabilities, which change over time". The preliminary framework proposed in this paper is relatively simplistic in its approach and does not cater for individual needs. However, welfare networks do exist, both formally, through their provision by local authorities and local non-government organisations, and also through the informal support networks of family, friends and by local neighbourhood networks. For this reason, a very broad statement has been added to the framework noting that:

'Welfare support will be required for the more vulnerable – this will be achieved by support from family and friends, by the spontaneous community response within the suburb using existing assets available, targeted support to communities by the official response and/or NGOs and/or through official welfare support, where and when available.'

This statement is recognised to be broad but is intended to be an aid to planning agencies, and for individuals to consider, pre-event, their personal and community levels of preparedness.

The framework also recognises that some parts of the region may be so heavily impacted by an event that they become uninhabitable, potentially for a period of months to years. For this reason, the caveat that "these standards do not apply in cordoned areas where people are assumed not to be sheltering" has been added as one of the footnotes to the framework.

The caveat that 'end user experience may vary' has been added to acknowledge that many factors may impinge on the provision of services; for instance, FM radio services may not be available in pockets near hills, the provision of food may be a greater than 2 km from the dwelling, and queuing may be required for some services. This caveat is included to temper expectations of end-users and alert them that there will be variable service levels following a major event, even with extensive planning or with the best endeavours of the infrastructure service providers themselves.

4.4.2. Limitations

As noted in Section 4.4.1, there are some clear limitations in the applicability of this framework for vulnerable individuals, where a similar approach is taken to the Sphere Handbook [2] in proposing a level of service, where (p7):

> ' … Conforming to the Sphere standards does not mean implementing all key actions or meeting all key indicators of all standards. The degree to which an organisation can meet the standards will depend on a range of factors, some of which are beyond their control.'

This aspect is also covered in Section 4(j) of this paper. For the emergency planners, a knowledge of the vulnerable communities and individuals will help to guide the formation of emergency plans, and the consideration of how to provide services to the vulnerable individuals. Further work is required on understanding how the more vulnerable will access services through the LoS given in this preliminary framework.

A second clear gap in this framework is the provision for larger facilities housing many vulnerable people in one location, such as prisons and retirement or rest homes. Most of these organisations are owned and operated by either governmental organisations (such as the Department of Corrections for prisons) or non-governmental organisations and businesses (such as a variety of providers for aged-care facilities). As the operators of such facilities, it is their responsibility to consider their responses, and LoS, in an emergency event, and is not covered further in this framework.

5. Discussion and conclusions

Regarding frameworks bringing together response and recovery targets, the NIST-related documents [19–21] use a framework which does define the recommended LoS for their own areas, alongside estimates of when infrastructure is assessed to be operational following an event. These examples are proof that LoS can be developed and publicised at city and state level. The LoS in these documents tend to be aimed at the infrastructure provider rather than the end-user communities, for example giving LoS for highways and airports rather than when food will be available at supermarkets.

The Sphere Handbook [2]; p. 9) details how human rights drive the standards created within that document. What is less defined is how these standards translate to a high-income context, an argument that Bross et al. [82] also use, noting that global minimum standards are 'hardly applicable' to high income countries. Power, broadcast and telecommunications services do not immediately appear to be essential for supporting life and are more of a high-income country 'requirement'. However, in high-income countries, electricity is required to power health facilities and emergency services and for enabling service stations to operate, which in turn can provide fuel for emergency generators at key facilities such as the hospitals, police stations and broadcast sites. The provision of such services necessarily span a mix of human needs across food and water supply and the provision of more specialist services such power to a medical facility. This is where a context-specific set of standards, or potentially 'emergency levels of service' may be desirable, for the utilities and emergency response agencies to plan for outages.

While some aspects of the framework are relatively developed and easily referenced, such as the water level of service, there is less material available to reference on aspects such as the distances to supermarkets, availability of access to healthcare, power supply and telecommunications. The creators of this preliminary framework have inserted preliminary inputs to the framework at this stage, however these under-developed aspects require further investigation.

The framework presented in here is preliminary. At this stage it is not a viable working document ready for adoption by the utilities, the emergency planning community or individuals within the region but is intended to provide a high-level basis for discussion with the utilities and key stakeholders to move towards an operationalised framework. It is not intended that following an event that

rigorous measures be taken to establish whether these LoS were achieved, or not. In fact, such moves would be considered counter-productive to the intentions of the framework as these could make the respective parties sensitive to the possibility that they will be measured (or perhaps judged) by specific instances of availability of services, post-event. The next step of development of the preliminary framework is to research, with key stakeholders including the critical infrastructure providers, how the LoS may be improved, appropriate to the respective sectors. Similar frameworks could be created at a high level by similarly placed practitioners in other regions of New Zealand, or internationally, for other contexts or regions.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Richard Mowll reports financial support was provided by QuakeCoRE. Richard Mowll reports a relationship with Wellington Lifelines Group that includes: consulting or advisory. This research is being carried out as 'action research'. The author is both the Project Manager of the Wellington Lifelines Group and the lead researcher. There is no perceived conflict of interest in these dual roles.

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