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INFRASTRUCTURE PLANNING EMERGENCY LEVELS OF SERVICE FOR THE WELLINGTON REGION, AOTEAROA NEW ZEALAND – AN OPERATIONALISED FRAMEWORK

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ABSTRACT

'Planning Emergency Levels of Service' (PELOS) are goals for the delivery of infrastructure services following a major hazard event, such as an earthquake or flood. This paper presents an operationalised PELOS framework for the Wellington region based on interviews with emergency and critical infrastructure managers and discusses important changes from the preliminary to the operationalised framework. A shared understanding of these PELOS will help Wellington region infrastructure providers, emergency management professionals and the potentially impacted communities plan for major events. PELOS for the energy, telecommunications, transport, and water sectors have been developed, and high-level interdependencies considered. The PELOS framework can be updated for other regions, by the critical infrastructure entities and emergency managers, using locally relevant hazard scenarios. In turn, this approach can inform the end-users (communities) of the goals of the critical infrastructure providers following a major hazard event.

INTRODUCTION

The infrastructure networks in the Wellington region of New Zealand are vulnerable to natural hazard events. For example, following a major local earthquake (a rupture of the Wellington fault), potable water network outages have been modelled to be between one and twelve months, and power outages between one week and six months [1-3]. Other key hazards that may impact the Wellington region include tsunami, flood and pandemic [3]. The impacts of Cyclone Gabrielle in February 2023 have demonstrated that prolonged infrastructure outages can occur from 'major hazard events in New Zealand, and that isolation by road, power outages, loss of water supply and telecommunications outages are issues that need to be planned for.

While some human needs in an emergency such as access to food and water can be linked back to human rights [4, 5], in the high-income context of Wellington, New Zealand, the need for a power supply (not normally identified as a human right) is inextricably linked with the provision of health care (for the functioning of the hospitals and the storage of medications that require refrigeration, such as insulin, at pharmacies), which is a human right [6]. The Sphere Association [7] linked the provision of human rights with standards for the delivery of services with a core belief that (p. 4) "[all] possible steps should be taken to alleviate human suffering arising out of disaster or conflict." While the Sphere Handbook covers sectors such as water, shelter, and the provision of food, it does not cover the provision of services such as electricity and telecommunications.

The concept of 'Planning Emergency Levels of Service' (PELOS) for the four infrastructure sectors (energy, telecommunications, transport and water) was introduced by Mowll, et al. [8]. In essence, a PELOS is a statement from a critical infrastructure entity on what its planned delivery of service during and after an emergency will be on the end-user, or community member. For example, the World Health Organisation's 'basic service' of 20 litres of water per person, per day, within 1 km of the dwelling could be used as a PELOS for water supply (discussed in Results). While the water supply PELOS is based on robust research and has been widely documented, for example by the World Health Organization [9], PELOS for the other sectors (energy, transport, telecommunications) are less well developed. The preliminary framework proposed by Mowll, et al. [8] allowed for the concept to be widened to the other sectors but was based only on literature and expert opinion. Engagement in the Wellington region has been carried out to update the preliminary framework to include input from critical infrastructure providers and key stakeholders such as emergency management professionals. The updated PELOS framework is thus an 'operationalised' framework based not solely on the literature review but also grounded in the realities of infrastructure and emergency management in the Wellington region. The operationalised framework now also includes airport, natural gas, solid waste, and port PELOS.

Lifelines groups' existence (or groups of critical infrastructure entities) are mandated by the National Emergency Management Agency (NEMA) of New Zealand (formerly the Ministry of Civil Defence & Emergency Management) [10]. According to NEMA, one of the key purposes of lifelines groups is (p35) to: "carry out risk reduction and readiness initiatives that involve more than one utility". As such, lifelines groups are vehicles for discussion on risk reduction emergency management activities across sectors (energy, telecommunications, transport, and water).

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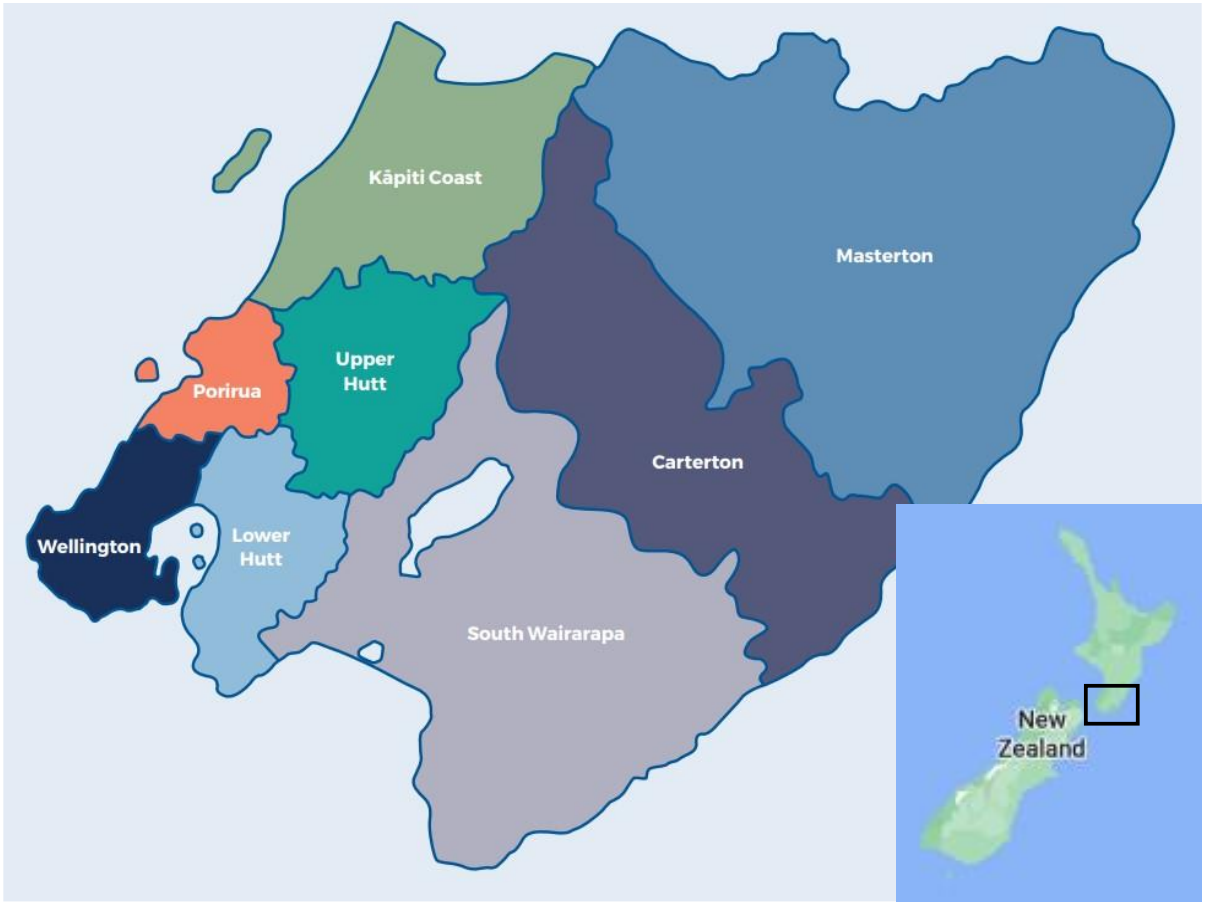

Figure 1: Local councils comprising the Wellington region, New Zealand

New Zealand's lifeline utilities are all independent operating entities, either central government (e.g., national-level State Owned Enterprises owning and managing infrastructure), local councils (owning and managing the local road and water networks), local government-owned entities (e.g., the owner and operator of Wellington's port) or private companies (e.g., a local electricity lines distribution company or a reticulated gas network owner and operator). The Wellington Lifelines Group (WeLG) has a voluntary membership, but all key critical infrastructure providers of the Wellington region are members (Wellington Lifelines Group, n.d.). One of its key purposes, as stated in its Charter, is to "facilitate discussion, particularly on hazard understanding and risk reduction measures on the Wellington Region's infrastructure". It is therefore an appropriate vehicle for discussion on PELOS.

The Wellington Region Emergency Management Office (WREMO) carries out the emergency planning function for the councils of the Wellington region (Wellington Region Emergency Management Office, n.d.-a). It is therefore the body with the mandate to lead discussions on the implications of PELOS and how they could interface with the community.

The work presented here is an updated and operationalised infrastructure-focussed PELOS framework that builds on the preliminary framework already published [8] and acknowledges groups of end-users of the infrastructure services. The next section of this paper provides an overview of the methodology used in creating the operationalised framework, which is presented in the following section. General issues relating to the framework are then discussed. Reasons for updating of the PELOS from the preliminary framework form are covered, following which interdependencies are addressed. Discussion on the key issues of how the framework was formed, the relationship between PELOS and a hazard event, engagement with the infrastructure entities and future research forms are then discussed before conclusions are drawn.

METHODOLOGY

Preliminary work

The theoretical foundation of PELOS was documented by Mowll, et al. [8]. In that paper, the concept of PELOS across all infrastructure sectors was introduced, and existing literature relating to PELOS identified. The preliminary framework was informed by literature created from discussions between emergency management professionals at WREMO.

The literature provided variable levels of information on PELOS for different sectors. There was excellent information for the water sector. While the literature provided information about impacts on a wide range of infrastructure sectors from hazard events, there were very few examples of PELOS developed for sectors other than water.. This led to a framework that, while grounded in the available literature, needed to be tested against the realities outlined by the critical infrastructure entities and emergency management staff.

The intention is that the framework be the basis for a shared understanding by all parties (infrastructure entities, the emergency management sector, and end-users), of realistic (based on knowledge of the relative vulnerabilities of the existing networks) goals for response and recovery (PELOS). While this makes clear the planning goals of infrastructure providers and the emergency management sector, to be useful, end-users need to be aware of the PELOS, and the potential infrastructure outages, and act upon them. For example,

pharmacies that are dependent on refrigeration for the storage of insulin and some medications need to be aware that there could be power outages for months following a major earthquake, and that the onus is on them to provide their own power – through solar panels and battery packs, or through a standby generator and fuel stocks. With a knowledge of the PELOS, the emergency management sector can then plan how it may work with the community to prepare them for outages, and work to address gaps, where they might exist.

CDEM Act (2002) update

While the interviews for this research were being carried out within the period September 2021 to May 2022, NEMA was carrying out consultation on a potential update to the Civil Defence Emergency Management Act No 33 [11] , New Zealand's key emergency management legislation [12]. During this period, the consultation on the update to the Act included early engagement on the potential for the inclusion of the concept of PELOS into the Act, including a proposal that all critical infrastructure entities should publicly state their PELOS every three years. Whilst this was only a proposal from NEMA for consultation, it must be acknowledged that interviewees may have considered that the wider outcome of the creation of a framework for the Wellington region was that it could potentially be adopted into a legislated requirement at some future date. This was not a specific question in the structured interviews, however in the wider environment, interviewees were aware of this potential development. The impact of this issue is explored in the Discussion section.

Interviews and focus groups (and analysis)

The lead author has a role within emergency management, has existing working relationships with the organisations engaged in this research and is carrying out academic study on PELOS. The use of the action research methodology [13] therefore allowed for the integration of these aspects together as a coherent methodology for conducting this research.

A wide set of organisations were engaged with, including staff from critical infrastructure entities and key emergency management bodies (at national and regional levels) from the energy, telecommunications, transport and water sectors, and from emergency management organisations. Semi-structured interviews and a community group workshop were followed by a workshop including all of the key stakeholders. Twenty-nine semi-structured interviews were carried out, of an hour's duration or less. Most of the infrastructure professionals interviewed held positions that are technical but include a liaison role with emergency management. This meant that those individuals were able to provide both technical and emergency management advice. Interviews were carried out confidentially, so any stakeholder could comment on any aspect, or infrastructure type, in the framework. The workshop was open, allowing all participants to comment on any aspect and hear the opinions of other attendees. In addition, to gauge the usefulness of the concept of PELOS to end-users of infrastructure services, one community group was interviewed using a different set of semi-structured interview questions. The community group was coalesced by one of the lifeline utilities, who use that group for various engagements regarding the delivery of their services, for a single session. The group was originally created with a commercial research and data collection company and represented a mixture of demographic characteristics. The input of that group reinforced that community vulnerabilities and how community members would access services are an issue that must be addressed in following work regarding emergency management in the region.

The questions posed in the semi-structured interviews and at the group workshop are included in the supplementary information of this paper. From the interviews, a long list of suggestions as to how to improve the PELOS framework was created.

In addition to the above, a small Advisory Group was formed to discuss the suggestions listed in the long list of potential updates. The Advisory Group was comprised of five emergency management professionals and consultants. This Advisory Group was small, to allow open discussion, and deliberately had a minority of technical staff on it, to ensure that community impacts of the PELOS would be highlighted, while being advised by technical input from engineers. The recommendations of the Advisory Group were taken into the final workshop, to minimise the work required in the workshop, and to ensure that each suggestion was allowed full consideration by emergency management professionals. The members of the Advisory Group were identified at the workshop, which allowed all workshop participants to know the level of expertise that was given to the consideration of the long list of suggested updates. This research was carried out under a high-risk ethics approval from Massey University (application SOA 21/40).

All interviews, for individuals and groups, were digitally recorded and transcribed. Coding was carried out using NVIVO software, a package that helps qualitative researchers organise and analyse information gathered from, for example, interviews. The quotations given in this paper use the information taken from these transcriptions.

Final consultation and decision making

In addition to the individual interviews, a workshop was held where all members of WeLG were invited, along with all people interviewed for this study. The final workshop was two hours in duration. At the workshop, all parties had opportunities to contribute to, and comment on, all other sectors, and to provide advice on the final PELOS identified for their own sector. The output of that workshop was the updated, 'operationalised' framework. This provided an integrated approach to PELOS and a better mutual understanding of each other's priorities and drivers. Each of the PELOS were discussed in turn, focussing on the suggestions made by the Advisory Group. Once each suggestion was discussed and any amendments to the PELOS agreed, discussion moved to the next suggestion.

OPERATIONALISED FRAMEWORK

The updated, operationalised framework is presented in

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Table 1:Wellington region –infrastructure planning emergency levels of service[i] - OPERATIONALISED FRAMEWORK for a MAJOR REGIONAL HAZARD EVENT

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: full functionality
Water	Minimum of 3 litres per person per day[ii], but recommended 20 litres per person per day, as stored at homes by individuals	15-20 litres of water per person per day[iii] within 1km of the house	80% of supply of potable water to 80% of customers[iv]	Full functionality towards a 'new normal'.
Roading[v]	Limited road use – only priority 1 routes[vi] or immediate alternates are open to emergency vehicles. Walking and cycling access to local medical centres and to Community Emergency Hubs is available.	Priority 1 routes are open and managed[vii], priority 2 roads or immediate alternates are open to emergency vehicles and, where resources allow, some public transport services run, where roads are open and available. Road access is available between dwellings and local medical centres and Community Emergency Hubs and between water stations and distribution points to enable water[viii] to be distributed.	Priority 1 and 2 roads are open and managed, priority 3 and 4 roads or alternates are open for emergency vehicles only and, where resources allow, some public transport services run.	Full functionality towards a 'new normal'.
Food and LPG (for cooking)	As stored in individual homes, provided by Fast Moving Consumer Goods (FMCG) suppliers who are still operating, or emergency food supply brought in with priority to vulnerable people	Access to a supplied supermarket or distribution point[ix] within 2km[x] of the dwelling following an event for urban areas	Access to a supplied supermarket within 2km of the dwelling in urban areas	Full functionality towards a 'new normal'.
Fuel[xi]	Diesel only: where access, power and resources allow, strict rationing[xii] to priority list of users (e.g., emergency services) using fuel storage in place at time of emergency.	Diesel only: where access, power and resources allow[xiii], strict rationing[xiv] to priority list of users (e.g., emergency services) using fuel storage in place at time of emergency and any immediate re-supply	Ability to transfer fuel from berth (at port) to tank farm(s). Priority, or selected, service stations are operating.	Full functionality towards a 'new normal'.
Power (electricity)	Households[xv] use from local sources[xvi] and response priority sites[xvii] (including hospitals and key facilities) and medical centres, pharmacies and supermarkets use own pre-arranged power supply for essential functions.	Households use from local sources and response priority sites (including hospitals, medical centres, pharmacies, and supermarkets) use own pre-arranged power supply for essential functions. 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 utility sites[xviiixix]. Ability to charge phones and tablets at a location within a local area such as a local Community Emergency Hub.	Full functionality towards a 'new normal', including street lighting[xx].

Telecomm-unications	EXAMPLE: Access to mobile data (via wireless) and untethered broadband at defined locations such as at Community Emergency Hubs[xxi]. (111 dialling only available from these locations.)	EXAMPLE: Mobile phone service in some locations, otherwise access only with untethered devices at Community Emergency Hubs. EXAMPLE: Supermarkets, service stations, banks and medical centres have internet access, where they have arranged for connectivity.	EXAMPLE: Access mobile data for almost normal data capability, with capacity constraints (congestion) at some times of day. Some landlines may be operable if the end-user has power.	Full functionality towards a 'new normal'.
	Satphone (and Starlink) usage where phones are charged.		EXAMPLE: Priority users have full service.	
Broadcast	FM radio – Priority Stations[xxii]: fully operational[xxiii]	Fully functional for priority radio stations, no TV	Fully functional for priority radio stations, no TV	Full functionality towards a 'new normal'.
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[xxiv].	Service, according to the 'two buckets' plan.	Full functionality towards a 'new normal'.
Solid waste	Zero level of service. Store waste at homes.	Activate debris disposal plan. Waste collections commence (even if from transfer stations or local skips/local locations.	Street collections commence.	Full functionality towards a 'new normal'.
Natural gas	Zero level of service	Critical customers re-supplied by isotainer and necessary equipment, where customer has made own arrangements.	Main pipelines re-commissioned[xxvxxvi]. Some critical customers are re-connected. Some suburbs have pipelines re-commissioned.	All customers re-connected[xxvii].
Port	Freight: zero level of service for days 0 to 7.	Freight: 450 TEUs ('Twenty foot Equivalent Units, or 20ft containers), or equivalent, per day[xxviii]. Fuel: ability to berth a ship at the fuel terminal by day 8.	Freight: 450 TEUs, or equivalent, per day. Other port functions may continue, if the port is less damaged and the transport and power networks are available.	Full functionality towards a 'new normal'.
Airport	The Airport should be able to operate a 1,200m long runway within 2 days of a major event[xxix].			If specialist equipment and material is available, a length of runway sufficient to land and take off civilian jet aircraft will be available[xxx].
Shelter	Shelter within own property or with immediate support network or at mass temporary accommodation sites.[xxxi]		Shelter within own property, with immediate support network or at alternative site.	

[i] These standards do not apply in 'red zones' or cordoned areas where people are assumed not to be sheltering.
[ii] Taken from Sphere Handbook, section 2.1, page 107: https://spherestandards.org/handbook/editions/
[iii] Taken from World Health Organisation: https://www.who.int/water_sanitation_health/emergencies/qa/emergencies_qa5/en/ (downloaded 3 May 2019) (20 litres), from Sphere Handbook, section 2.1, page 107: https://spherestandards.org/handbook/editions/ (15 litres) and from Wellington Water's '80-30-80' strategy (20 litres).
[iv] Taken from Wellington Water's '80-30-80' strategy
[v] Following an event, assessments of damage may change priorities.
[vi] See Wellington Region Earthquake Plan (WREP) of December 2018 for information on priority routes. Any nominated routes will be adapted in a response by the Controller, based on the observed damage to the roading network.
[vii] Restrictions may be in place for non-emergency vehicles (to manage safety issues).
[viii] For Community Infrastructure Resilience (CIR) water project details, see https://www.wellingtonwater.co.nz/your-water/emergency-water/above-ground-emergency-water-network/how-the-emergency-water-network-will-operate/
[ix] Distribution points are listed in the Wellington Region Earthquake Plan (WREP) of December 2018 from WREMO. See Appendix G1.
[x] The Sphere Handbook (item 6.3) has a target of less than 5km. https://spherestandards.org/handbook/editions/
[xi] The fuel line is relevant as long as diesel is used for powering generators, earthmoving machinery and delivery trucks.
[xii] For security issues of fuel supply during rationing, see section 3.4.3 of the National Fuel Plan: https://www.civildefence.govt.nz/assets/Uploads/publications/National-fuel-plan/National-Fuel-Plan-Final-March2020.pdf
[xiii] This includes resources to inspect and re-open service stations, and the resources required to operate them.
[xiv] For security issues of fuel supply during rationing, see section 3.4.3 of the National Fuel Plan: https://www.civildefence.govt.nz/assets/Uploads/publications/National-fuel-plan/National-Fuel-Plan-Final-March2020.pdf
[xv] Including medically dependant people located at home.
[xvi] Example, household solar panels, or generators.
[xvii] For a list of priority sites, see WeLG/WREMO/WELA 'lifelines response priorities: 8 February 2019'
[xviii] As included in the WeLG/WREMO/WELA Key Utility Sites document of 2016.
[xix] Power supply (from the grid) requires generation and national transmission assets to be operational.
[xx] Power re-supply depends on the availability of materials and equipment, internationally (for example, the order period for transformers in 2021 was 9 months), for which the appropriate stakeholders (lines companies) should consider their arrangements.
[xxi] assuming the CEH's system has capacity
[xxii] See https://getthru.govt.nz/radio-stations-to-listen-to for a list of the priority radio stations.
[xxiii] See http://transition.fcc.gov/pshs/docs/csric/WG2B-MSRC-Best-Practice-Update-Final-Report.pdf section titled "Vulnerability Assessment Guidelines".
[xxiv] See Mowll, R., Stewart, C., Neely, D. P., Brenin, M., Fisher, M., Loodin, N., & Hutchison, S. (2022). Creating a post-earthquake emergency sanitation plan for the Wellington region, Aotearoa New Zealand. *Australian Journal of Emergency Management, July 2022.* https://knowledge.aidr.org.au/resources/ajem-july-2022-creating-a-post-earthquake-emergency-sanitation-plan-for-the-wellington-region-aotearoa-new-zealand/
[xxv] Natural gas supply from a reticulated network requires national transmission assets to be operational.
[xxvi] Road access and fuel and contractor availability are required to allow access to critical gas assets. For local supply, gas must be available from transmission delivery points.
[xxvii] All customers must have a gas professional re-connect supply to network.
[xxviii] If viable wharf area is available, and the ship operators are able to interface with that, and there is a discharge location to the road network. This level of service would be either using Roll-On-Roll-Off ferries where available, and able to interface with the wharf and operations, or geared ships (ships with their own cranes), i.e., vessels and/or operating plant that does not rely on third party services.
[xxix] Weather and navigation instrumentation constraints may impact operations.
[xxx] Weather and navigation instrumentation constraints may impact operations.
[xxxi] See https://spherestandards.org/handbook/editions/ for additional information/direction. Assumes staying within own home or property.

The following assumptions and caveats were agreed in conjunction with the stakeholders:

- 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 Non-Governmental Organisations (NGOs) and/or through official welfare support, where and when available.
- The PELOS shown in this table refer to potential official response. Latent local and community capacity will contribute to all aspects of the response.
- These recommendations may not be achievable and are only presented for planning purposes. Actual hazard events and the resultant impacts due to the nature and extent of the event 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.)
- All the above 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.

RESULTS – GENERAL ISSUES

In this section, the key findings from interviews are presented, including both aspects where the interviewees suggested changes and aspects that didn't require change. Some PELOS, including for water and roading required relatively minor changes while for telecommunications major change was required.

While this is not a quantitative study, it is useful to note the scale of the responses received on key issues regarding the use of the framework. These are presented here, with opinions given during the interviews.

Usefulness of the framework

Of the 29 interviewees, all expressed the opinion that the concept of PELOS was useful to them in considering post-disaster delivery of services. All interviewees stated that they were happy to engage further on the issue, demonstrating a willingness to advance thinking, and to carry out further analysis, on the concept. Some representative opinions expressed included that the concept would allow the critical infrastructure entities to better understand that "what people are thinking [is] important (in an emergency)" (Interview 11), in other words, the issues that the infrastructure entities should be targeting as their service provisions in an emergency. Another interviewee thought that there should be aspirational targets, "set to survival" (Interview 10), as a minimum level, or starting point, and to allow sectors such as health and business to start up. More than one respondent noted potential difficulties in the setting of any PELOS due to complexity in integrating the concept with other infrastructure asset management factors such as cost of delivery (of PELOS) and balancing the "tensions between environmental and service delivery…" (Interview 06). The implementation of the concept, rather than the simple creation of the theoretical concept, was therefore seen as a challenge that would have to be carried throughout central and local government policy and operational structures to ensure that any PELOS were considered against other infrastructure management factors such as quality of (general) service delivery or cost. These are factors that can only be analysed at system-level, which is outside of the scope of this paper. The information provided in the PELOS framework would therefore provide one strand of information for overall decisions on the investment in upgrading critical infrastructure for delivering PELOS.

Availabilities of other frameworks

Regarding other existing frameworks or PELOS, responses highlighted various sector-internal documents such as Government Policy Statements for the transport sector in New Zealand [14], with mentions in such documents of 'resilience', however none of those documents contained specific, measurable, PELOS, largely as these statements are normally intended to be policy- rather than operationally-focussed. Some interviewees from infrastructure organisations noted internal work carried out within their organisations on potential PELOS however, apart from Wellington Water [15], none of the internal PELOS work had been published.

Public release of the framework?

For many of the interviewees from the infrastructure entities, there was a desire to avoid releasing any framework into the public domain, to avoid implying any linkage between a PELOS framework and a commitment to achieving the stated PELOS should an event happen 'tomorrow'. This is particularly relevant as past reports released by WeLG [1, 2, 16] demonstrate that, in the event of a rupture of the Wellington fault, there would be parts of some networks where it would not be possible to achieve the PELOS stated in the operationalised framework. To mitigate the infrastructure providers' concerns, it was agreed that caveats and assumptions should be included with the operationalised framework that "end-user experience may vary" in the delivery of services, to signal that not all post-event PELOS will be achievable in all locations. Additionally, the framework is not intended to imply any commitment by the various stakeholders at the time of the interviews. These issues were discussed at the group workshop, where it was reinforced that the PELOS are goals for delivery, not commitments to achieve a particular level of service in an as-yet-unknown future emergency. Ultimately, the Group confirmed that the public release of the framework was acceptable.

Hazard event that the framework is based on

At the suggestion of the Advisory Group for this project, the title of the operationalised framework was updated to include the words 'for a major regional hazard event' to make it explicit that the PELOS presented in the framework apply to a major event. As one respondent (Interviewee 01) put it:

> "I think the bigger challenges are around the bigger events, obviously, because most smaller events can have levels of service restored within a few days and they become more of an inconvenience in most instances for people rather than a general threat as the system is able to absorb those disruptions to smaller events. It's the medium to large events which really are in alignment with earthquake and tsunami."

Much research and emergency management planning in the Wellington region, for example the Wellington Earthquake National Initial Response Plan [17] has been based on the scenario of a 'worst case' earthquake such as a rupture of the Wellington fault. "That's been a good proxy for almost anything" (Interview 06). However, for a useful and useable framework, the PELOS should be hazard-agnostic, as human

needs for water, food etc. are the same, no matter what hazard event has occurred. Thus, the target levels of service may remain be the same. The consequence of this is that the PELOS are based on the consequences of major infrastructure outages, not on the likelihood of such outages. Further, events that impact infrastructure services for short durations (i.e., a few hours) would not trigger the need for PELOS. Some events that do not impact the whole region may have severe impacts on smaller geographical locations, and in such locations the PELOS will be relevant to such events. In this way, while the framework is intended to be used for major regional hazard events, the PELOS may also be relevant to some aspects of smaller events.

Timeframes (one week, one month, three months and beyond)

The timeframes given in the framework (for the first week, the rest of the first month, for the second and third months, and 'beyond') were discussed with interviewees. All interviewees that expressed an opinion considered these planning timeframes to be acceptable for emergency response in the Wellington region. As Interviewee 01, whose response was similar to those of a few other interviewees, put it:

> "A week fits into the psychology of outcome expectancies of what people believe they have an ability to control. So, it's not so big an 'ask' if they can't plan or prepare for that. The rest of that following structure around the first month makes it again another achievable timeframe as far as what people can plan for, what we can anticipate and then further out, it gets harder to predict what the future can look like, but these guidelines really help shape what we can be working towards… It makes it easier to get my head around what we should be planning for, and to what extent we should be helping our communities to mitigate this."

Similarly, interviewees indicated that the timeframes provide a basis for a series of phases for any operational emergency management planning periods. It was noted, however, that the timeframes should not be seen as rigid milestones for delivery, but as planning guidance on the trajectory of effort and delivery of services. There were suggestions from three interviewees that a timeframe of '1 day' should also be included, however both the Advisory Group and wider workshop attendees agreed that this would create the impression that service delivery would be achievable within a day (which is largely not the case, while staff attend to their own home situations), and this suggestion was therefore not taken further.

Feedback received from more than one interviewee indicated that the proposed levels of service for the timeframe beyond three months in the preliminary framework were poorly worded. These proposed a level of service of, "80% of supply to 80% of customers", but interviewees noted that this was ambiguous as it was unclear whether it referred to 80% of the delivery volume or 80% of the time. Interviewees also suggested that it would be unwise to suggest a division between end-users. The suggestion from one interviewee was that the phrase be changed to "full functionality for a 'new normal'". The wording 'a new normal' matched recovery thinking in the Wellington region, as it recognises that a recovery could have taken place that does not replicate the conditions prior to the emergency event, but does deliver services differently, or the community has adapted in some way, that is still acceptable to the impacted parties. The 'full functionality' wording is used to indicate that the utility services should be delivered to the 'business as usual' levels of service. While this phrase is non-specific, it points towards the fuller delivery of services following the emergency event, and acknowledges that the location of, and other aspects of delivery of the service, may be different to how and what services were delivered prior to the event. The suggested wording was discussed in both the Advisory Group and at the workshop and found to be acceptable. Alongside the presentation of the results of the interviews/workshops, we highlight how these results might inform a revised framework.

Services that are not mentioned

There are many cases of services that are not detailed in the framework. Examples could be water or power supply to priority facilities (e.g., medical facilities) or access for emergency services to respond to events. If not explicitly mentioned, the inference is that such services will not be delivered by the infrastructure provider post-event, and therefore that the respective organisations (health and emergency services in this example) should consider, pre-event, how they will deliver their own services during a potential outage. This could be through the storage of water in robust containers, through the acquisition of generators and sufficient fuel, or through modified emergency response principles/plans. In this way, the framework can be used to both guide emergency planning (in the short term) and inform discussions between key organisations and the infrastructure providers on what PELOS might be achievable if investments in the resilience of infrastructure were made.

RESULTS – SECTOR-SPECIFIC ISSUES

Interview and workshop participants were asked the questions listed in Appendix 1 (supplementary information), covering both the applicability of the framework. They discussed sector-specific issues they found relevant. The following section outlines the results of these interviews and workshops. The long list of changes proposed in the interviews and workshop are included in the supplementary information of this paper. Trivial changes (such as the inclusion of 'and cycling' after walking, for active transport to interface with PELOS) were readily incorporated. More major changes were discussed with the Advisory Group and agreed upon at the final workshop. The following is a description of the main points, discussed by sector.

Water

Due to the information campaigns on the storage of water prior to an event carried out by both Wellington Water and WREMO [18-21], the concept that households should be self-sufficient for water for the first seven days following an event was not challenged, neither were the PELOS previously identified by Wellington Water for the remainder of the first month and 'beyond' [15]. While the above PELOS were created and adopted for the Wellington metropolitan area (Wellington Water's operating area), these PELOS were considered acceptable for the other urban areas of the Wellington region. The operationalised framework therefore does not change the water PELOS proposed in the preliminary framework.

Of the comments that were received during interviews, one of the key concerns raised was the ability of residents of the Wellington region to fetch water from 1km away from their home, particularly if they are collecting for more than one person (probably meaning multiple trips per day carrying/transporting 20 kg of water). As Interviewee 06 put it:

> "… you're trying to cut down that distance as much as possible, you know, not only is there physical exertion, but there's the risk of injury, you need proper containers to be able to do it, containers that are robust enough so that when you drop them that, half way through your

> walk you haven't… lost all your water because your containers have been destroyed along with your morale".

While the WHO basic access standard is well established, its applicability to the Wellington region context is worthy of separate future research, as the perception of some interviewees was that a significant proportion of the Wellington region population would struggle to carry that quantity of water that distance, particularly considering Wellington's hilly topography. Most water bores and streams are in the floors of valleys, meaning that those living on the sides of, and on top of, hills, have to carry the water uphill.

Road access

The preliminary framework used a Wellington-specific emergency plan for the order in which roads would be prioritised to open following a major event. From stakeholder feedback, it was suggested that the framework could be equally valid, but more applicable nationally, if the New Zealand 'One Network Road Classification' (ONRC) [22, 23] were used instead. The ONRC mapping provides a classification of roads on the network, from 'national high volume' to 'arterial' and 'residential'. This mapping helps the road controlling authorities understand the relative significance of a particular type of road (including their alternates), including likely maintenance activities and cycles. Both the Advisory Group (described in Methodology) and the workshop decided that the bespoke approach of the mapping of priority routes for an emergency event was preferable, as it prioritised access to key facilities such as fuel depots or the hospital, which the generic Waka Kotahi ONRC mapping does not. Priority routes include major routes and access to key sites.

Several updates were made from the preliminary framework to the operationalised framework. An update in the operationalised framework for road access is the inclusion of the explicit statement regarding access between dwellings and local medical centres and community emergency hubs for 'the rest of the first month': 'road access is available between dwellings and local medical centres and Community Emergency Hubs and between water stations and distribution points'. This was included to clarify that while road access to medical centres and emergency hubs is a goal within a month, it will not be immediately viable in the first week post-event, other than in locations where the roads are either less damaged, or debris have been cleared (either by a contractor working on the roads, or by community members clearing the roads themselves to regain road access). This was considered by both the Advisory Group and the workshop to be an acceptable approach.

Opportunities to run public transport on the road network were highlighted by two interviewees (07 and 23). Firstly, where access is available on key routes for emergency vehicles (as was included for in the preliminary framework), the potential to also run buses (where available) on those emergency routes was included in the operationalised framework. Secondly, the potential to run bus services within suburbs that have road access within them, but no access to outside the suburb, was included (Interview 23). This could take the form, for example, of a bus service running a short set loop around the suburb, aiding water collection, or food collection from the local supermarket (where open/available). Such an arrangement would require the presence of a bus, bus drivers, fuel (or, where relevant, power) and available roads. This option was included in the operationalised framework due to the potential for enabling greater mobility around suburbs, but also to highlight that bus services on full business-as-usual scheduled routes are unlikely to be viable while road access is compromised.

On the suggestion of Interviewee 23, a simple update was to include the words 'and cycling' in 'walking and cycling access'. This change relates to the viable use of cycling in active transport to and from medical centres and community emergency hubs, where road access is compromised to the level that motorised vehicle access would not be achievable.

Five interviewees noted that road access is a key enabler for other infrastructure sectors to make inspections and repairs on other critical infrastructure networks. While an exhaustive interdependency analysis has not been carried out for this research (see also the section on interdependencies), the need for road access, and the relative likelihood of access by certain times (i.e. within a week, a month, or three months) was factored into the timeframes given by the other sectors. Roading sector participants were all aware of the importance of road access for other infrastructure sectors, and for communities to access essential goods and services, and to allow movement around the region.

Fast Moving Consumer Goods (FMCGs) (and Liquified Petroleum Gas (LPG))

The preliminary framework includes the following PELOS for food: "access to a supplied supermarket or distribution point within 2 km of the dwelling following an event for urban areas". The 2 km distance was not challenged by interviewees. Interviewee 13 noted the concept of "15-minute neighbourhoods, where the provision of essential services within 15 minutes walking time of a dwelling encourages more active transport and provides more (socially) connected communities [24]. While the 2km distance is not a clear match with the 15-minute neighbourhood, the interviewee noted the broad alignment between the two measures, and was supportive of the 2km distance, particularly as (pre-event) the majority (around 95%) of dwellings across of the region are within 2km of a supermarket. The 2km distance was adopted for this framework.

As Interviewee 18 put it: "it's a matter of being pragmatic... my general experience of… people in emergency situations is they will normally start to form around and look out for each other…". This opinion acknowledges that there will be periods during the response when road access and public transport will not be available to all, and that vulnerable people will require assistance to access essential supplies such as food. This provides an opportunity for the emergency management professionals to (pre-event) work with key communities to encourage assistance to the vulnerable during key infrastructure and supply outages.

While the above addresses access to FMCGs, in line with the preliminary framework, access to LPG has been included with FMCGs. LPG is used by many households in the Wellington region for heating bar-b-ques, and therefore is a useful alternative means of cooking.

Fuel

Two key issues were highlighted during the interviews for the fuel sector. The first was that in the days (and potentially in some parts of the region, weeks) following a major event, "it's no point having a service station that works perfectly and no one can get to it, right?" (Interview 14). The PELOS in the operationalised framework of having operational service stations by the start of the second month following a major event corresponds to the times to restore road access to most service stations in the region, as detailed by the Wellington Lifelines Group [2].

The key fuel required for response and recovery activities will be for earthmoving machinery and generators, which typically require diesel. Diesel fuel, as a product, is less flammable than petrol, and therefore has different storage and transportation requirements. The cells in the operationalised framework were therefore amended to make explicit that within the first month the response effort would focus on the re-supply of diesel, with its easier transport and storage, and the likely demand for it for emergency services and response. Therefore, petrol resupply will not be a key focus of the immediate response.

The second issue raised was that, particularly following a major earthquake, the tanks and operating systems of fuel stations would have to be checked by skilled technicians, and the PELOS should allow for time for such checks to be carried out. The availability of skilled technicians was seen as a key input to achieve the PELOS, and the words "where access and resources allow" were added into the framework. While such skilled assessment would be required across all sectors (e.g. checking of structures and buildings), this request was a specific one for the fuel sector, noting a specific need in that sector.

One workshop participant noted that, in a major fuel outage, security would be required at service stations, as there could be the potential for disorder where fuel is being rationed only to priority users (such as emergency services and medical needs). For this, it was agreed to reference in the footnotes to the framework the National Fuel Plan which has guidance on the provision of security at service stations in an emergency event.

Power (electricity)

While critical facilities such as hospitals, medical centres and supermarkets were explicitly referred to in the preliminary framework, pharmacies were not, an issue that was brought up during the interview process. Interviewee 15 (a critical infrastructure staff member) noted: "I often get calls from people who say, 'how can I keep my medications safe?' And it's generally insulin." As some medications such as insulin and some anti-psychotic drugs require refrigerated storage, pharmacies were therefore included in the PELOS for power supply.

The inclusion of a PELOS for street lighting in the 'beyond' (beyond three months) was intended to make explicit that street lighting will not be a priority for the restoration of services, compared to other services, within the first phases of a major response and recovery effort. This prioritisation was highlighted by several interviewees, typified as follows: (for domestic supply) "normally we'd be thinking lights, fridge… and your radio, TV" and "streetlights is probably a little bit further down the list" (interview 11).

One aspect that was highlighted was that at-home medically dependent people should be referenced in the operationalised framework. For these, the phrase 'households use from local sources' was intended to cover the need for all households to consider their need for power supplies. Further elaboration was not highlighted as required.

The framework was also strengthened by including footnotes noting that for the electricity lines (distribution) network to perform, they must be supplied by the transmission network.

Finally, for power supply, noting the need for spare parts following a major event, at the workshop it was agreed to make explicit that the distribution lines companies should consider how they will arrange essential goods such as spare poles, wires, and substations. For this, the wording was made explicit that "the appropriate stakeholders (lines companies) should consider their arrangements".

Telecommunications and broadcast

Telecommunications sector expert interviewees highlighted the relative resilience and adaptability of the telecommunications network infrastructure with, for example, often multiple routes of fibre optic cable, on a highly connected network [25]. This does not mean that it will not be broken in hazard events in the Wellington region, however it does demonstrate that fibre optic networks are often relatively robust. However, as Interviewee 21 put it, "power is critical in a fibre network". Without power, the telecommunications network will not operate. In the Wellington region, many of the exchanges and key items of infrastructure such as 'switches' (which are effectively the computers that log calls and carry out some billing functions) generally have standby generators installed in case of power outages, which does create a level of resilience. However, battery packs on cell towers generally last no longer than 24 hours, but generators at telephone exchanges are normally designed to last considerably longer. Additionally, the end-users of the network must have power to operate the devices installed at homes and facilities, such as modems or routers, computers, phones etc. In the case of a major power outage, alternative power will be required to all elements of the network for it to be operational. While battery packs will initially keep cell sites working, generally within 24 hours of a power outage, alternative power supplies will be required. Fuel will be required at all sites which are using generators, where road access may (following a major earthquake) be compromised. These factors have the potential to limit the operation of the network in the days and weeks following a major event.

The preliminary framework proposed that (mobile) texting services be prioritised ahead of (mobile) voice calling. This was based on a dated understanding of mobile networks where, during the use of 2G and 3G networks the equipment at a cell tower was different for texting, voice calls and data. In later generations of mobile technology, including 4G and 5G, all services (text, voice, and data) are performed by the same equipment. Interviewee 20 noted that:

> "If we bring that cell site back on in, get it functional, all services would be running. Not just triple one, and not just triple one and text, not just triple one, text and voice, but all services will be enabled. That's how the technology works".

Delineating levels of service based on the function provided at a cell site is therefore not appropriate. Despite this, perhaps the highest priority use of the telecommunications network is the ability to make emergency calls (in New Zealand the emergency number is 111), and this service was considered by the interviewees to be one that should receive the highest prioritisation.

Instead of focussing on which service is provided first, feedback from interviewees suggested that effort should be on where power could be provided, and then identify potential services based on that. Community Emergency Hubs (CEHs) are "pre-identified places for the community to coordinate their efforts to help each other during and after a disaster" [26]. The lists of CEHs show that a majority (69% on 13th January 2022) were schools. In New Zealand, "the vast majority of the schools, like really, the vast majority of schools have fibre connections to them, and… they've got really serious Wi-Fi capability within the campus" (Interviewee 16) to enable teaching to be carried out using untethered devices (such as small laptop computers and tablets). Assuming that the exchanges already have standby generation (which the majority do), if power can be ensured at these schools (both to enable the wireless network and fibre optic transmission, and to allow the charging of untethered devices such as phones and laptops), and the schools are

connected to exchanges using fibre cables, the CEHs could be used as locations where members of the community could use the telecommunications network. This would be a relatively limited number of sites (a total of 88 in the Wellington region, as of 13th Jan 22) that, with power, could be used for a minimal level of service for the first week following an event. This would mean that, according to this PELOS, emergency (111) calling could only be made from such locations during the first week.

Another issue highlighted from the interviews was the need to have telecommunications working at key locations, particularly at supermarkets and banks, to allow the sale and purchase of food and essential provisions by electronic transfer (credit and debit cards). This was not included within 'the first week' as the PELOS for food supply is for food stored at individual homes to be consumed in the first week. Internet access for supermarkets and banks was explicitly included in the PELOS for telecommunications for 'the rest of the first month'. As the bank and supermarket chains are privately owned and operated, the expectation from the emergency management sector indicated during interviews, was that the supermarkets and banks should provide their own power generation in an event, and the words 'where they have arranged for connectivity' were added.

For 'the second and third months', the PELOS shown in the operationalised framework shows 'access mobile data for almost normal data capability', which assumes that any necessary repairs to the telecommunications network could have been made by this time, and that power supply has been provided to key sites such as cell sites and exchanges (whether by networked power or from generators and fuel supply). The results of the interviews did not change this PELOS from the preliminary framework.

Acknowledging the evolving capabilities of satellite-based services (such as Iridium and, more recently, Starlink), 'satphone' services were again included in the framework, noting that such services will work "where phones are charged".

The use of non-cabled services such as provided through satellite links addresses the issue of potential loss of cabled (fibre optic and other) services in the pre-event telecommunications networks in the PELOS articulated in the framework.

Finally, discussion on the telecommunications PELOS centred on the fact that there has not been a chance to discuss the PELOS widely with the telecommunications sector as fewer interviewees were available from this sector. As such, the PELOS given in the operationalised framework are only an example of what kind of statement could be created, so the word 'EXAMPLE' was added prior to each telecommunications PELOS in the framework.

Sanitation

No interviewees made comment on the PELOS provided in the preliminary framework for sanitation. This probably reflects that the 2021 emergency sanitation plan was developed collaboratively by WREMO, Wellington Water and Wellington Regional Public Health, promoting self-sufficiency by households in a combined outage of the wastewater and, initially, road systems, which therefore covered the key organisations that would be most likely to comment on this aspect. The 'two buckets' approach (one for 'wee' one for 'poo') promoted in that plan [27] was therefore taken forward to the operationalised framework. 'Wee' and 'poo', referring to urine and faeces, were highlighted as appropriate language for use in the Wellington community in that plan.

Shelter

In New Zealand, shelter, or accommodation, is not seen as a lifeline utility, and is not included within the New Zealand definition of 'critical infrastructure' [28]. Instead, it is often considered under the general banner of 'buildings'. As such, it does not sit well within a framework for infrastructure levels of service. However, we considered it important to include in the operationalised framework due to the key role it plays for individuals. One change suggested by interviewees was that the PELOS should show that by the beginning of the second month post-event that mass accommodation sites should no longer be required, with people being encouraged to "shelter at their own property, with immediate support network, or at an alternative site". Such moves would depend on the habitability of dwellings, which would in turn depend upon the availabilities of water, power etc., which would be decisions taken by individuals based on their personal circumstances. The goal of not requiring mass accommodation was accepted at the final workshop. This assumes that the need for mass accommodation would be phased out over the first month.

However, as Interviewee 06 indicated, this may be problematic for residents of apartment blocks, particularly in areas of high-density apartment housing, if areas of Wellington are 'red zoned' or collapse or damage to nearby buildings make apartment blocks unsafe for occupation. This is an issue that requires further research.

It was suggested at the workshop that 'evacuation' could form an additional line (as a stand-alone service) in the operationalised framework, as this may be required where apartment blocks are not occupiable. This was discussed at the workshop but rejected, as evacuation is dependent on road and/or port or airport functionality, which are already covered in the operationalised framework.

Port

Except for the use of ferries for passenger services, the activities at Wellington's CentrePort are generally a step removed from services to individuals. Container operations service most of the freight needs for the community, fuel supply comes through the port and the export of logs is a sizable economic activity, employing many people throughout that supply chain, but few of these services directly supply individuals. Therefore, the operation of most activities at the port cannot be linked to direct impacts on the 'end users' (individuals in the community) but can be linked to the next step in the delivery of services. Any PELOS developed for the port would need to be acknowledged to be relevant to those that run operations at the port but framed in a way that reflected the needs of end-users.

It was discussed during interviews that, following a major event such as an earthquake, the port would have to be inspected for damage before operations could re-commence [17]. For this reason, the PELOS for the port 'for the first week' has been put as a 'zero level of service' for freight to allow those inspections to be carried out. Following that though, and in line with NEMA's emergency response plan for a major earthquake [17], the movement of "450 TEUs (Twenty foot Equivalent Unit shipping containers), or equivalent, per day" was included as a PELOS 'for the rest of the first month'. This PELOS could be carried out using the freight decks of the roll-on-roll-off ferries operating between the North and South Islands of New Zealand or using geared ships (ships with their own cranes for loading and unloading). This acknowledges that in a power outage the container cranes normally operational at the port would not be able to function as they are powered by electricity, and the generators that

would be required to power them would be too large to be practicably installed. At the workshop the availability of roll-on-roll-off ferries (RORO) in an emergency event was discussed. The words 'where available and able to interface with wharf operations' were added, to make clear that this type of vessel would be a critical requirement for this PELOS to be achievable. For 'the second and third months', the PELOS for the port recognises that it is preferable for economic activity to be recommencing, so specifies that "other port functions may continue, if the port is less damaged and the transport and power networks are available".

Finally, for the port, acknowledging the PELOS relating to fuel supply includes that the "ability to berth a ship at the fuel terminal by day 8" would cover the services provided by the port, but not the owners of the fuel delivery infrastructure (pipelines etc.), which is owned by multiple organisations.

The above PELOS were discussed at the workshop, where it was agreed that the above changes were acceptable.

Airport

As for the port, activities at the airport are generally a step removed from day-to-day activities of members of the community, except for passenger services. However, like the port, PELOS have been included in the operationalised framework that would inform emergency response activities. According to work carried out by the Wellington International Airport, the northernmost section of the runway at the airport is founded on rocky material, so it is likely that even in a major earthquake that the runway damage would be minimal. Similarly, as the northernmost section of the runway is higher than most of the southern end of the runway, it is less vulnerable to tsunami inundation than the southern section [29]. Therefore, following advice from interviewees and as agreed at the workshop, the PELOS included in the operationalised framework is that: "the Airport should be able to operate a 1,200 m long runway within 2 days of a major event. Weather and navigation instrumentation constraints may impact operations." The 1200 m length is significant, as it is sufficient to land and take off turboprop aircraft and some military freight aircraft. The turboprop aircraft are significant as they regularly service routes between regional airports in New Zealand and are therefore commonly operating at Wellington Airport. Also significantly, all aircraft that operate through Wellington Airport can, if fuelled appropriately prior to departure from the previous airport, land and take off from Wellington Airport without having to refuel there. While the PELOS for the airport do not reference the use of the terminal and other infrastructure at the airport (which may, or may not, be available), the PELOS does indicate the potential for emergency response operations to be carried out. The note regarding weather and instrumentation constraints relate to navigational and other airport systems that require power to operate, however all aircraft using the airport can operate on visual and manual landing systems.

Noting that civilian jet aircraft also use the airport, a PELOS for 'beyond' (four months) was included, in the case that runway and airfield repairs for the southern end of the runway could be made within the first three months following a major event.

Gas

There were no PELOS included in the preliminary framework for natural gas (mainly methane) supply. Several interviewees (06, 19, 24, 25) noted this omission, and therefore natural gas was included in the operationalised framework. Interviewees indicated that in the week following a major event it is most likely that damage to the networks will result in a 'zero' level of service for gas. This will impact key facilities such as the hospitals (which use gas for heating) and commercial users, and it will also impact those that use gas at home for cooking. For those at home, and with access to a BBQ (separate from the reticulated gas system), the 'food and LPG' PELOS is intended to provide the gas for the use of barbeques, allowing people that have them to heat food and boil water.

The PELOS for 'the rest of the first month' acknowledges that reticulated gas services may be damaged during a major event, and that their repair will take some weeks [2]. Therefore, gas supply is referred to as being delivered without the use of the gas network – by isotainers, which are freight container-sized and compatible tanks in frames containing, normally, LPG to priority sites, where end-users have made their own arrangements. As LPG has a different "calorific value and consistency as natural gas" (interview 24), the PELOS includes the words 'necessary equipment' as condensers and different nozzles must be fitted to gas boilers to allow them to be converted for LPG use.

The PELOS for gas for 'the second and third months' is "main pipelines re-commissioned. Some critical customers are re-connected. Some suburbs have pipelines re-commissioned." The interviews highlighted that the gas reticulation companies can re-commission their networks, potentially in line with the timeframe given in the framework, however each property can only be re-connected to the network by a gas professional such as a gas fitter (to check all gas fittings in the house and turn back on any pilot lights). In reality, this is an operation that requires considerable manpower, and could take months to complete for all properties with a gas connection.

As discussed, and agreed at the workshop, in line with the footnote for electricity, a footnote was also added for gas that states: "Natural gas supply from a reticulated network requires national transmission assets to be operational."

INTERDEPENDENCIES

The issue of interdependencies – how critical infrastructure sectors rely on each other for their successful operation [2, 30-32] – was considered throughout the creation of the operationalised framework. For example, the dependency of the telecommunications sector on a power supply was discussed in Results. Interviewee 15 noted that "our levels of service are somewhat irrelevant if they don't align with other service providers".

One of the key interdependencies is road access. For examples, as Interviewee 03 said "roading is the key, and the others will then all work concurrently once you get roading done. Because even water is really important, but without your roads, you're not going to get your water around." On a similar theme, Interviewee 07 said "from a lifelines perspective, fuel, food, water, power, you need a road to get to those things to maintain whatever it is. And if you haven't got the road then you certainly got to fly it in, or boat it in, something".

Power is another key interdependency. For telecommunications, Interviewee 21 noted that "power is critical in a fibre network" (see also Results). It is also critical for running water pumping stations and fuel stations. This is an aspect that Interviewee 20 (from a critical infrastructure entity) focussed on: "… we would have to be able to plug in generators where required, and keep running the generators where they are existent, and ensure that there is an increased or enhanced level of fuel supply for those particular generators".

For the creation of the operationalised framework, interdependencies were considered, as the framework was developed, in discussion with the interviewees. The interdependencies considered are demonstrated in **Error! Reference source not found.**.

Table 2: logic for key interdependencies

	Operationalised PELOS	**Associated PELOS**	**Interdependencies?**
Food: first week	"As stored in individual homes."	Requires no supply chain.	No interdependency issues.
	"Food supply brought in with priority to vulnerable people."	Depends on emergency response plans, which cannot guarantee supply. Such plans would require any logistics resources that are available at the time of the event and may not use conventional supply chains. Such emergency supply chains would probably not use roads for access, as these are assumed to be damaged in large-impact scenarios (see Wellington Lifelines Group [2] for earthquake example).	As such, no interdependency issues.
Food: for the rest of the first month	"Access to a supplied supermarket or distribution point within 2km following an event for urban areas."	Road access: "Priority 1 routes are open and managed; priority 2 roads are open to emergency vehicles." Power: "… response priority sites (including hospitals, medical centres, pharmacies, and supermarkets) use own pre-arranged power supply for essential functions." Telecommunications: "Supermarkets and banks have internet access, where they have arranged for connectivity."	Road access: Most supermarkets are near priority 1 or 2 routes; therefore, no interdependency issues. Power: no interdependency logic issues. Telecommunications: supermarkets may arrange telecommunications connectivity for electronic payments via wireless or satellite-based systems. No interdependency logic issues.
Fuel: up until 'the rest of the first month'	"Diesel only: where access, power and resources allow, 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."	No re-supply required (by logic) for this PELOS, therefore no interdependencies.	No interdependency issues.
Fuel: the second and third months	"Priority, or selected, service stations are operating."	Port: As for 'the rest of the first month', ship can berth (by 'day 8'). Fuel: Ability to transfer fuel from berth (at port) to tank farm(s). Roads: "Priority 1 and 2 roads are open and managed; priority 3 and 4 roads are open for emergency vehicles only" (most service stations are on priority 1-4 routes). Power: 'Power to response priority sites and key utility sites' (which include service stations). Telecommunications: As for 'the rest of the first month', service stations may use mobile data for internet access.	Port, tank farms. No interdependency issues. Road access: Most service stations are on priority 1 to 4 routes. No interdependency logic issues. (This can be demonstrated in a parallel mapping of the PELOS – see ???paper.) Power: no interdependency issues. Telecommunications: no interdependency logic issues. If all of the above PELOS are operational, including the tanks in the tank farms, the stated PELOS for fuel for the second and third months would be viable.
Water: for the rest of the first month	"15-20 litres of water per person per day within 1km of the house"	Roads: "Road access is available between… water stations and distribution points."	No interdependency issues.
Water: the second and third months	"80% of supply of potable water to 80% of customers."	Roads: "Priority 1 and 2 roads are open and managed; priority 3 and 4 roads are open for emergency vehicles only". This will facilitate a proportion of water system repairs. Power: "Power to response priority sites and key utility sites" (which include the major water pumping stations).	Roads and power: no interdependency issues.

DISCUSSION

This section covers key lessons from the consultation process and limitations of the operationalised framework.

Operationalising the framework

In general, most of the participants agreed with most of the contents of the preliminary framework. This demonstrated alignment with the literature, where it was available. Why was there generally such alignment? It is likely that the relative universality of humans' water needs, and the strong evidence from WHO and the Sphere Handbook standards (see Results) led to few comments on the water sector. While the literature for the roading sector was less prescriptive, there appeared sufficient related examples in the literature that the interviewees were happy to adopt the PELOS given in the preliminary framework.

Significant gaps in the preliminary framework, such as for the port, airport, and natural gas, were addressed through the knowledge and experience of the interviewees and workshop attendees. Such gaps needed to be addressed as there were few examples given in the literature, and the concept of PELOS, across infrastructure sectors, is relatively new. This is where most of the updates from the preliminary framework are to be found – through the inclusion of these additional infrastructure types. Additional key changes were within the telecommunications sector, where the PELOS included in the preliminary framework were outdated (based on older telecommunications technology). Otherwise, the PELOS for the other infrastructure sectors (roading, water, food) were only slightly altered from the preliminary framework.

While the PELOS created in the operationalised framework were created for this region, many of them could be adopted, or adjusted (perhaps for level of service, or for timeframes given in the framework) by other regions or localities. The exception for considering the framework at just regional level was roading. Discussion on this issue centred on whether to use Wellington-region-specific bespoke priority routes mappings, or whether national-level road classification mappings should be used. As discussed in Results, from the discussion, agreement was reached that PELOS created for an emergency event would be stronger if they used the emergency plans. This approach was acceptable for the attendees of the final workshop, and therefore was adopted into the operationalised framework. Therefore, if other regions have road prioritisation mappings, the whole framework could be adopted or adapted for used elsewhere.

Relationship between PELOS and a hazard event

As outlined in Results – general issues, the hazard chosen for this operationalised PELOS framework was a 'major regional event' but using a rupture of the Wellington fault as a basis for understanding the scale of potential impacts on critical infrastructure, and therefore the infrastructure outages that may impact the community. While the choice of a 'major event' is critical to understanding the nature of the hazard that the framework is addressing, the important aspect is that the stated PELOS should be relevant to any actual event, whether it be an earthquake, tsunami, volcano (ash fall) or other hazard. The PELOS in the framework, for example the delivery of 15-20 litres of water, per person, per day, is seen in literature as a basic standard, which is a human need independent of whatever hazard event has occurred. Using a major hazard event (in this case the rupture of the Wellington fault) as a basis for analysis means that the operationalised framework should cover the consequences of that event (as modelled). As human needs (such as access to water, healthcare etc.) will not be different in any hazard event causing infrastructure outages, the PELOS can be seen to be hazard-agnostic. The PELOS are therefore based on the consequences of outages, not on their likelihoods or specific features. While actual events may have different timeframes for response and recovery, this does not change the planning work that can be carried out pre-event by the critical infrastructure entities. This is where the PELOS helps the entities consider what events they are mitigating against, and therefore create plans that cover a range of potential outage scenarios.

Smaller events, such as short-term floods or wind events, are less likely to require reference to the PELOS framework due to their smaller and/or short-term impacts, and the critical infrastructure entities are likely to be delivering their services well within the PELOS.

Engagement with the critical infrastructure entities has been key

Much of the key engagement on this research/project has been with the critical infrastructure entities themselves. They know their networks well, the organisational and regulatory context in which they operate and, having participated in WeLG projects, are aware of the relative vulnerabilities of their respective networks to major events such as a rupture of the Wellington fault. Their willingness to collaborate on this work is testament to the ongoing work of WeLG and WREMO and their own professionalism. Building up such a working relationship takes time (WeLG has been working on such issues since 1993) but reaps rewards in good engagement between relevant organisations, across infrastructure sectors. The creation of an operationalised PELOS framework is a challenging initiative, as it requires organisations to be open about the relative vulnerabilities of their infrastructure. Again, the benefit of having an organisational structure (a lifelines group) in which to facilitate such discussions has been clear.

The impact on this research of NEMA's consultation about updating New Zealand's emergency management legislation (see Methodology) at the same time as the interviews for this research were being carried out cannot be quantified. This may partly be because NEMA's consultation on the inclusion of PELOS in an updated Act was only discussed by NEMA at a summary (broad-brush) level, so that specifics of what might be included in an updated Act were not necessarily well understood. Interviewees may have thought that they should be proactively involved, as NEMA's consultation may lead to change anyway. However, having already agreed to participate in such a project, as outlined in the Wellington CDEM Group Plan [3], it was very likely that all parties would be willing to be engaged on the subject. It should also be acknowledged that all key stakeholders have been engaged on other WeLG/WREMO projects since 1993, collaborating on a range of resilience-related projects. This project may have been viewed by them as simply another WeLG/WREMO project.

As a rough guide to the effort required to create this operationalised PELOS framework, the lead author (who has carried out the literature review and conducted the interviews and analysis) has been able to do this as part of a part-time role over three years. This may be less time-consuming for other regions wishing to develop their own PELOS framework, as the example presented here is available as a starting point.

Future research required

is research highlighted several areas in which further research may be required.

When would people decide to leave their homes due to loss of services? These could be considered as 'tipping points'. Such

tipping points will be different for each person. The loss of just one service (such as water or electricity) will mean that some may wish to temporarily leave home to a location where those services are available. Others may choose to remain in place, despite the loss of several services. The tipping points of different people is an aspect that should be better understood.

How will vulnerable groups such as the disabled and the immobile be able to access services such as water or food? Decisions on access for these groups are likely to be taken at the household level. This is a key point for the emergency management sector to consider how assistance to vulnerable communities may be planned for. A related issue is the walking distances that Wellington residents could manage in an emergency event. While the Sphere Handbook [7] refers to 5 km from dwelling to marketplace or distribution point, the operationalised framework points to 2 km. What are the distances that Wellington residents could manage, considering the challenging topography?

Other issues requiring further research include the impacts of the loss of access for emergency services – the ambulance, fire service and the police. How emergency fuel supply is carried out where road access and service stations are impacted, (the New Zealand national fuel plan [33] provides some thoughts, but does not cover the specifics of supply). How such a framework could be created for rural areas? Little was found in the literature to guide thoughts on PELOS regarding the above issues.

CONCLUSION

A study was undertaken to better understand whether levels of service identified in the literature, and developed into a preliminary framework, aligned with the critical infrastructure entities' staff perceptions of anticipated PELOS following a disaster. Through the processes outlined in this paper these concepts were explored with critical infrastructure entities and the emergency management sector, resulting the creation of an operationalised PELOS framework. This will help key groups understand the objectives of the critical infrastructure providers and the emergency management sector in a response. As indicated in the Discussion, there would be value in understanding the gaps between PELOS (goals) and modelled deliveries of services. Where there are gaps of delivery between the PELOS and the outage mappings shown by the [2], this would allow stakeholder to be specific in planning for such an emergency and to work towards the mitigation of such gaps. Making this framework public, along with any representation of the gaps between PELOS and deliveries of services will provide community members with a realistic picture of disruptions to essential services in a major event. This would clarify to them why it is necessary to plan for such disruptions, for example by storing food and water at home.

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