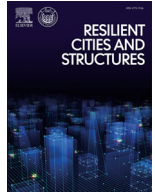




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Full Length Article

Creating a ‘planning emergency levels of service’ framework – a silver bullet, or something useful for target practice?


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ARTICLE INFO

Keywords:

Infrastructure

Resilience

Recovery

Emergency management

ABSTRACT

‘Planning Emergency Levels of Service’ (PELOS) are service delivery goals for infrastructure providers during and after an emergency event. These goals could be delivered through the existing infrastructure (e.g., pipes, lines, cables), or through other means (trucked water or the provision of generators). This paper describes how an operationalised framework of PELOS for the Wellington region, New Zealand was created, alongside the key stakeholders. We undertook interviews and workshops with critical infrastructure entities to create the framework. Through this process we found five themes that informed the context and development of the PELOS framework: interdependencies between critical infrastructure, the need to consider the vulnerabilities of some community members, emergency planning considerations, stakeholders’ willingness to collaborate on this research/project and the flexibility/adaptability of the delivery of infrastructure services following a major event. These themes are all explored in this paper. This research finds that the understanding of the hazardscape and potential outages from hazards is critical and that co-ordination between key stakeholders is essential to create such a framework. This paper may be used to inform the production of PELOS frameworks in other localities.

1. Introduction

1.1. Planning emergency level of service (PELOS) overview

Many infrastructure providers use the term ‘level of service’ to describe features of infrastructure, through ‘asset condition, performance and other relevant outputs’ Edwards [1]. While the term, and use of levels of service is well understood in the management of infrastructure, Mowll et al. [2] found that there are few examples, internationally, of utilities publicly stating measurable and timebound levels of service that are specific to an emergency response or recovery. The work carried out on the West Coast of the USA [3–5], which led to the creation of the NIST Guide [6] provide an example of how goals for performance for a city or state can be articulated, however few other regional or district-wide examples can be found. There are examples of standards provided for emergency- and low-cost environments provided by the World Health Organization [7] and the Sphere Association [8], however these are either exclusively for the water sector only, or cover only some infrastructure sectors, and in a way that it most applicable to emergency- and low-cost environments.

One of the few examples of a publicly available emergency level of service is Wellington Water’s delivery strategy of ‘20 litres per person per day of drinking water within eight days of a major shock event’ [9]. Such a statement demonstrates Wellington Water’s planning intention (hence the use of the word ‘Planning’), and their goal for delivery in an emergency. While Wellington Water was able to source information from well researched and authoritative sources [7,8] in developing their level of service, other infrastructure sectors (energy, telecommunications and transport) are not rich in publicly stated measurable and timebound Planning Emergency Levels of Service (PELOS). Some organizations have stated PELOS that are hard to measure due to statements such as “nearly always”, with one example being from the (provisional) Customer Levels of Service of Waka Kotahi New Zealand Transport Agency [10]. Another example is to have levels of service that are useful for the sector, but not necessarily relevant to the end-user, using network-averaging outage measures such as SAIDI (System Average Interruption Duration Index) and SAIFI (System Average Interruption Frequency Index), where network outages are calculated for electricity lines distribution companies using formulae to demonstrate the reliability of a network (example, Wellington Electricity [11]). These examples

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<https://doi.org/10.1016/j.rcns.2023.05.002>

Received 17 November 2022; Received in revised form 27 March 2023; Accepted 6 May 2023

Available online 23 May 2023

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demonstrate that some infrastructure providers have internal measures that are useful for their respective sectors, but less relevant to the end-users.

While advances have been made in the measurement of the concept of ‘community disaster resilience’, the resilience of components of the transport network and the quantification of ‘resilience’ [12–14], working towards the provision of PELOS can be used to plan for levels of service in a response that provide for the immediate needs of communities.

The UNDRR uses the term ‘critical infrastructure’ to define ‘(the) physical structures, facilities, networks and other assets which provide services that are essential to the social and economic functioning of a community or society’ [15]. Most other OECD countries and bodies also use the term ‘critical infrastructure’ for example the European Union [16], Australia [17] and the USA [18]. In this paper, the term ‘lifeline utilities’ is used interchangeably with ‘critical infrastructure entities’. This is because the former term has been used in New Zealand since the early 1990s [19], and is included in the names of regional organisations such as the Wellington Lifelines Group (WeLG). However, the National Emergency Management Agency (NEMA) is consulting (as of August 2022) on a potential legislation update that may change the term in New Zealand to be ‘critical infrastructure entities’ to bring New Zealand into line with international terminology.

Different countries use different mechanisms to outline the obligations of the critical infrastructure entities to provide resilience. For example, in the USA, the U.S. Department of Homeland Security [20] notes that ‘Infrastructure security and resilience programs can be voluntary, regulatory, or a combination of both. In the United States, voluntary programs are most common.’ In Australia the legislation is more prescriptive, with the obligations of the critical infrastructure entities stating that such entities must ‘have, and comply with, a critical infrastructure risk management program...’ which must identify, minimize or eliminate or mitigate risks [21]. In New Zealand, the Civil Defence Emergency Management Act No 33 [22] states (Clause 60) that: “Every lifeline utility must... ensure that it is able to function to the fullest possible extent, even though this may be at a reduced level, during and after an emergency”. This statement is laudable in its intent but is unmeasurable and does not provide key guidance on what critical infrastructure entities are expected to be able to achieve in terms of risk reduction actions or in a response to an event. While building codes do provide a basis for the design of specific buildings or components of infrastructure such as bridges [23], they do not provide a system-wide standard for the performance of infrastructure, or sector-wide resilience standards as networks such as road surfaces and buried pipes generally do not have network-level measurable performance targets. This paper outlines the process taken to develop a preliminary PELOS framework informed by information in the literature [2], into an operationalized PELOS framework, [2] alongside key considerations related to the creation and understanding of PELOS. These considerations are presented as five themes that were derived from a series of interviews and workshops, these being:

- Interdependencies between critical infrastructure sectors;
- the vulnerabilities of community members to the outages from infrastructure failures, including those too old or too young, or otherwise unable to, for example, collect water from 1 km away, and other community members that will struggle to interface with the PELOS;
- the responsibilities, and actions of parties (for example the critical infrastructure entities) in working with PELOS;
- the willingness of key parties to collaborate on the creation of the PELOS framework; and
- the flexibility/adaptability of the delivery of infrastructure services following a major event.

After this introduction and overview of the context, the methodology for updating the preliminary framework to an operationalized one is covered in Section 2. The key issues and themes (noted above) are explored

in Section 3. Discussion points and engagement issues are covered in Section 4, with conclusions drawn in Section 5.

1.2. The wellington region context

The Wellington Lifelines Group (WeLG) has existed since 1993 and has run various projects with the critical infrastructure entities on understanding the risk to the region and the potential impacts of hazard events (Wellington Lifelines Group, n.d.), working towards proactive mitigation of risk to infrastructure. The Group includes all the critical infrastructure entities working within the Wellington metropolitan area (which is defined in this paper as covering the Kapiti Coast, Porirua City, Upper Hutt City, Hutt City and Wellington City areas – see Fig. 1).

The purpose of the Wellington Region Emergency Management Office (WREMO), amongst other objectives, is to create a space where collaborative emergency planning can be carried out between the key stakeholders in the region, including the councils, emergency services, central government, *mana whenua* (local Māori, the indigenous peoples of New Zealand), the critical infrastructure entities and the community.

Through past studies, the risk of, and representative outages from, a major hazard event impacting the Wellington region are relatively well understood [24–26]. The aforementioned studies focus on a major earthquake impacting the region (for the 2019 study, specifically a rupture of the Wellington fault), although the [27] lists the five top hazards impacting the region as pandemic, earthquakes, flooding, tsunami and storms. As will be seen, some stakeholders consider the Wellington fault to be representative hazard, which usefully provides a ‘worst case’ scenario for analysis and planning.

While these reports have improved the understanding of risk, only the WeLG Programme Business Case [26] contains a proactive plan for long-term risk reduction. While providing excellent information, the above documents do not directly inform response and recovery intentions or planning for the region. In order to address this, a plan to create PELOS was included in the WREMO ‘Group Plan’ [27], in order to give all utilities a consistent basis for planning immediate response and early recovery activities following a major event. The creation of PELOS by critical infrastructure entities was intended, through the WeLG/WREMO project to demonstrate the intentions of individual infrastructure providers in an emergency to three key sets of stakeholders: the other critical infrastructure entities, the emergency management sector (to aid planning for emergencies) and finally to the members of the community, (to aid transparency of levels of infrastructure vulnerability).

At a national level, the National Emergency Management Agency (NEMA) “provides leadership in reducing risk, being ready for, responding to and recovering from emergencies” [28] in New Zealand. One major task carried out by NEMA during 2021 and 2022 was to work on an update of New Zealand’s emergency management legislation [22]. As noted above, the CDEM Act is relatively non-specific in what level of resilience should be achievable by critical infrastructure entities, or their assets. One aspect, relevant to this research/project, was that one of the changes consulted on by NEMA for an update of the Act was that ‘lifeline utilities must publicly state their PELOS’. This consultation commenced just before the research interviews commenced, making participants mindful of a potential legislative change regarding PELOS. The potential impact of this aspect on this research is discussed in Section 3.4.

2. Creating a PELOS framework: methodology and process

2.1. Research philosophy

Action research is a methodology used by practitioners to investigate an aspect of their work, within their colleague group. It is seen as a living process, generating knowledge from experiences. McNiff [29] sees that action researcher/practitioners work in environments with other practitioners in which negotiation is required to progress, and where

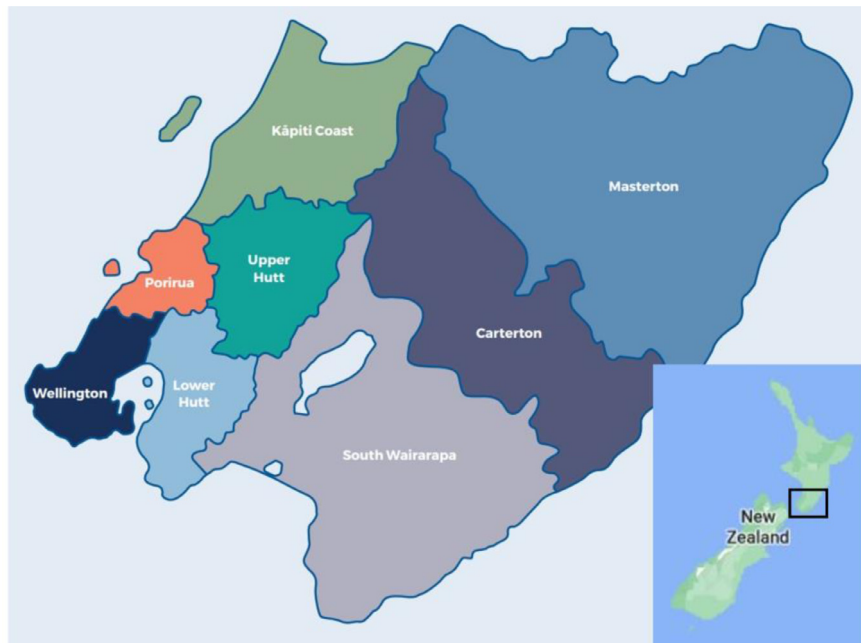


Fig. 1. - Local councils comprising the Wellington region, New Zealand.

learning (for both researcher and practitioners) is therefore created. The action research methodology was a clear fit for this research and has been the one taken. Comments on the appropriateness of this approach are made in Section 4.5.

This research draws on 29 in-depth interviews carried out for this research, held between September 2021 and May 2022, and from a workshop carried out in May 2022. Interviews carried out for this research/project were carried out with staff who work for critical infrastructure entities, who have knowledge of both how utilities function and of how these functions interface with emergency management (through the risk reduction, readiness, response, and recovery phases), and with emergency management professionals. The critical infrastructure interviewees were spread across the four (as listed in the Civil Defence Emergency Management Act No 33 [22]) sectors of energy, telecommunications, transport and water. The lead author holds working relationships with the relevant organizations, again matching the action research methodology. Details of the interviews and analysis methods are given in Sections 2.4 and 2.4.2.

This research was approved by the Massey University Human Ethics Committee (Ethical Approval SOA 21/40).

2.2. Process taken to create the PELOS framework

The process taken in creating a PELOS framework in the Wellington region is summarized in Fig. 2. The bands across the diagram (preliminary work, engagement, decision-making, finalization and release) are taken as the main headings for the following parts of this section.

The National Institute of Standards and Technology [6] [NIST] outlines the process of ‘defining goals and objectives’ (p4) for emergency management as including:

- ‘establish long-term community goals
- Establish performance goals
- Define community hazards
- Determine anticipated performance
- Summarise results.’

NIST defines this as one step of a six-step process to planning for community resilience. The process outlined in this paper assumes that community hazards are already known, to some degree, as detailed in

Section 1.1. The process in this paper does not run to the extent of outlining how each critical infrastructure provider, or the emergency management sector, should create a plan for the delivery of performance in an emergency, leaving this step to other emergency management processes, both at the critical infrastructure entities and within the emergency management sector. This paper, instead, focusses on NIST’s ‘establish performance goals’ step, or for this paper, the creation of PELOS.

From an emergency management standpoint it would not be appropriate to plan for the delivery of individual infrastructure services to a community without considering the delivery of all services. For example, the absence of just one utility – for example a water service – would put stress on a community. The loss of other services (road access or power supply) could necessitate evacuation from their homes for some community members. For this reason, the framework incorporates all the key utilities. In this way, the framework can be viewed as a ‘whole’, allowing people to anticipate how they might plan for the temporary absence of each critical infrastructure service, with some knowledge of how long, and how many services together, may be unavailable.

2.3. Preliminary work

2.3.1. Literature review

The first step of the process of creating a framework of PELOS was a literature review. As outlined in Section 1.1, the literature review for this research, detailed by Mowll et al. [2], demonstrates that there is a relative wealth of literature on the needs of humans for water supply, and good sources of outage modelling and network modelling for the energy, telecommunications and transport sectors, however, it largely highlighted that despite the sources that support the creation of such PELOS, and PELOS frameworks, and guidance on how this can be carried out, there are few publicly stated PELOS. Some guidance literature (largely practitioner, rather than research-led), informed the creation of preliminary PELOS. For any other region carrying out a similar study, there may be a need to update the literature review with newer information, and to also establish whether any of the local critical infrastructure entities already have stated PELOS (or equivalents) that are measurable and timebound.

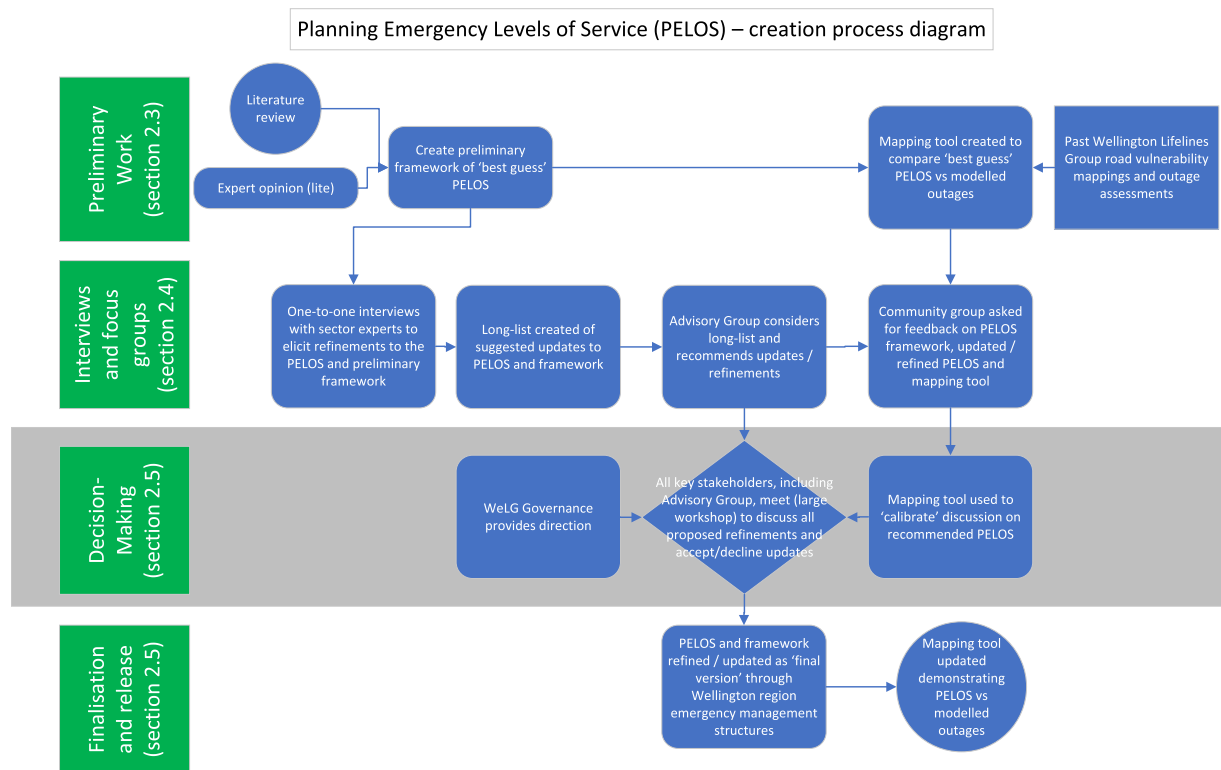


Fig. 2. PELOS creation process diagram.

2.3.2. Choose a representative hazard

In order to create a framework of PELOS for the Wellington region, a representative major hazard event initially needed to be identified, to allow for a scale of event to be envisaged when articulating new PELOS. However, on working through the process of the creation of the operational framework it was found that PELOS were appropriate for ‘any’ major regional hazard event. For example, the PELOS for water, for ‘the remainder of the first month’ of 20 L of water, per person, per day, a highly researched level of service, should be relevant for whether there has been an earthquake, a tsunami, a large flood, or any hazard. The need of each person is still the same, and the target service should still be the same. Therefore it was necessary not to nominate the exact hazard (earthquake, tsunami, flooding etc.,) rather it was necessary to establish the scale of the event used for planning purposes. For this framework, a rupture of the Wellington fault was initially nominated as the representative major event, to allow stakeholders to use a modelled major event as a basis for establishing the PELOS, however as noted above this quickly became peripheral to the actually nominated PELOS. How the hazard event interfaces with the selection of PELOS is explored further in Section 3.3.2.

2.3.3. Create a preliminary framework

As detailed by Mowll et al. [2], a preliminary framework was created through discussions between three emergency management professionals at WREMO. Where literature sources were available, the PELOS in the preliminary framework were based on the literature. Where no literature was available, ‘best guess’ PELOS were created, informed (where available) by the infrastructure outages modelled by WeLG [26] and balanced against ‘best guess’ human needs (as detailed in Section 2.3.2). While the process taken to create the preliminary framework was not a ‘perfect’ process in terms of having access to ‘perfect’ information or to a bedrock of available literature, it was considered by the practitioners to be a starting point to create a framework of PELOS and provided a sufficient demonstration of what the intended framework was meant to

look like, making it easier to explain the concept with stakeholders in following discussions.

2.3.4. Create a preliminary mapping tool

A preliminary mapping tool was created, in order to establish whether the proposed PELOS were very easily achievable, hard, or impossible to achieve, and therefore what PELOS should be included in an operationalized framework. Where used, this also gave stakeholders during interviews and the final project/research workshop an understanding of anticipated infrastructure outages, and their impacts on communities, in an emergency. The infrastructure outage information used in the modelling was from the WeLG Programme Business Case of 2019 [26], which used a rupture of the Wellington fault as its hazard event. The development of this mapping tool will be the basis of future research.

2.4. Interviews and focus groups

2.4.1. Conduct interviews

The creation of the operationalized PELOS framework was carried out through a series of interviews with key stakeholders from the critical infrastructure entities and the emergency management sector, followed up by a workshop with all stakeholders. Engaging with the stakeholders in this way allowed the framework to be updated to incorporate the experience and knowledge of the technical experts and key stakeholders.

As outlined in Section 2.1, the lead author has a role within emergency management, and existing working relationships with the organizations engaged in this research and is carrying out academic study on PELOS. The use of the action research methodology [29] therefore allowed for the integration of those two aspects together as a coherent methodology for conducting this research.

Staff from a wide set of organizations, including members of the Wellington Lifelines Group and key emergency management bodies (both national and regional), were contacted by e-mail, inviting them to participate in this research. Initial approaches were to the lead author’s

Table 1
Interviewees - number and sectors.

| Sector | Number of interviewees* | Group or individual |
|--------------------------------|-------------------------|---|
| Emergency Management | Ten | All single-person interviews, except one two-person interview |
| Energy | Eight | All single-person interviews |
| Telecommunications / broadcast | Five | All single-person interviews |
| Transport | Ten | Eight single-person interviews, one interview with two interviewees and one with three |
| Water | Four | Three single-person interviews, one interview with two interviewees |
| Group interviews | Two | One community group interview (eight attendees), one workshop involving all key stakeholders (28 attendees) |

* Note that some interviewees covered more than one aspect – such as a council employee who could talk to both emergency management and the water or roading PELOS.

working contacts at the Wellington Lifelines Group, however in some cases the contacted staff passed on the interview request to colleagues. Effectively this produced a saturation of available interviewees for this subject. A total of 29 interviews were carried out for this research, each being of one hour or less in duration, between the months of September 2021 and May 2022. These were semi-structured, with 26 of them held on a one-to-one basis.

All interviewees were provided a copy of the literature review and preliminary framework, as presented by Mowll et al. [2], for background information/context. The remaining three interviews were also semi-structured, but held with two or three interviewees, where the relevant organizations' functions necessitated input from more than one staff members who separately had technical knowledge of their infrastructure network or an understanding of the emergency management context. Most of the infrastructure professionals interviewed hold positions in their organizations 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. Numbers are summarized in Table 1.

Interviews were carried out under confidence so that interviewees could talk openly about any of the sectors, whether they were engaged in that sector or not. Due to this aspect, although it was more likely that interviewees would refer, at least in part, to their own sector, the information source for any one PELOS could have come from a person from any of the infrastructure sectors. In addition, to gauge the usefulness of the concept of PELOS to end-users of infrastructure services, one community group was interviewed. The community group was assembled previously by one of the region's critical infrastructure entities, through sampling carried out by a professional research company. This ensured that the community group provided a good representation of views from around the region, and from different demographics. One of the results of the interviews was a long list of suggestions as to how to improve the PELOS framework. All interviews and the community group interview were one hour in length.

Rather than taking the results of all the individual interviews directly into a workshop with all attendees, a small Advisory Group was formed to discuss the suggestions listed in the long list of potential updates. The Advisory Group consisted of five people, from emergency management, a council plus there was one independent consultant. This Advisory Group was small, to allow open discussion, and deliberately had a minority of engineers on it, to ensure that community impacts of the PELOS would be highlighted, while being advised by the technical input the engineers could provide. The recommendations of the Advisory Group created a short list of updates, which were taken into the final workshop. This process minimized the work required in the workshop and ensured that each suggestion was allowed full consideration by emergency management professionals.

2.4.2. Data analysis

All interviews, for individuals and groups, were recorded and transcribed. Coding was carried out using NVIVO software, using the nodes shown in Table 2. NVIVO is a software tool used by qualitative re-

searchers to order and analyze information gathered on a research topic. The number of files denotes the number of interviewees that referred to the code. The number of references demonstrates the number of times that a particular node was referred to during interviews. As can be seen, there was a greater level of response on issues such as hazards used for analysis and interdependencies, but fewer comments on aspects such as the use of PELOS in other organizations or personal preparedness.

This study is qualitative, however it is useful to note some of the numbers of responses on issues, as it provides relative levels of interest, or responses, on issues. For example, it is interesting to note that participants were happy to talk across sectors. Of comments made on sector-specific issues, 18 comments were made by interviewees relating to their own sector, while 19 comments were made about sectors that were not theirs. This demonstrates that the interviewees were aware of either their dependence on other sectors (as an interdependency requirement) or their impact on others, such as a transport provider's knowledge of how the loss of road access will impact food deliveries. This was particularly evident where five non-roading interviewees commented on road dependencies and three non-telecommunications interviewees commented on telecommunications dependencies. Conversely, in some sectors only those that worked in the sector commented on it (e.g., airport and natural gas). Where delineations between which interviewee groups commented on which issue are pronounced, they are commented on in the sections below.

2.5. Decision-making and finalisation

In order to progress development and agreement on the framework, decision-making is an important component of the process. The first key decision milestone for the framework was to agree to running this project at all. This was carried out at a workshop prior to the data collection phase in 2018 which was a part of the creation of the Wellington CDEM Group Plan [27]. At this workshop, the high-level objectives of creating a PELOS framework were stated, from which agreement was gained to proceed with the project/research.

A second set of key decisions were taken at the end-of-project workshop, which was the final part of the research data collection phase, but a key part of the WeLG/WREMO project, in which the WeLG Chair and the Steering Committee were in attendance. This workshop provided the decision point for WeLG on whether to finalize the framework. All members of WeLG were invited to this two-hour workshop, along with all people interviewed for this study. 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, 'operationalized' framework.

At the workshop, the preliminary mapping tool was reviewed, to calibrate discussions. It would have been relatively worthless to have created PELOS that were impossible to achieve, even with high levels of investment, and therefore seeing the achievability of the PELOS with existing infrastructure allowed for discussions to be held on realistic PELOS. Each of the PELOS were then discussed in turn, focussing on the suggestions made by the Advisory Group. Once each suggestion was

Table 2
Coding nodes and references captured.

| Node | Number of files (interviewees commenting) | Number of references captured (times that this code was referred to) |
|--|---|--|
| General issues: | | |
| PELOS framework usefulness | 10 | 15 |
| PELOS general comments | 4 | 10 |
| PELOS used in other contexts / organisations | 1 | 1 |
| General comments | 8 | 17 |
| Hazard events used | 10 | 10 |
| Interdependencies | 10 | 19 |
| Methodological issues | 0 | 0 |
| Personal preparedness | 0 | 0 |
| Timeframes (first week, first month etc.) | 14 | 26 |
| Use of Sphere Handbook | 3 | 4 |
| Present utility assessments | 1 | 1 |
| Sector-specific issues: | | |
| Airport | 1 | 1 |
| Broadcast | 1 | 1 |
| Food and LPG (Liquid Petroleum Gas) | 3 | 12 |
| Fuel | 3 | 6 |
| Natural gas | 2 | 8 |
| Port | 2 | 3 |
| Power (electricity) | 5 | 18 |
| Roading | 8 | 26 |
| Sanitation | 0 | 0 |
| Shelter | 2 | 4 |
| Telecommunications | 7 | 22 |
| Water | 3 | 3 |
| Process and release issues: | | |
| Visualization of outputs/outages to be released? | 28 | 28 |
| Publicly release the framework? | 29 | 29 |

discussed and any amendments to the PELOS made, discussion moved to the next suggestion. Discussion was held on the potential public release of the framework, either by WeLG or in an academic paper (such as this paper).

The framework was then finalized through agreement within the Wellington Lifelines Group Steering Committee, and through the emergency management governance processes of the Wellington region.

3. Key themes and issues

The following are five key themes that were developed from the interviews carried out for this research. They cover the aspects of interdependencies, vulnerable communities, emergency planning considerations, willingness to collaborate on this work, and flexibility/adaptability of the delivery of services. While these themes fall outside of the contents of the PELOS framework, they were overarching considerations for the development and implementation of the framework. These themes will also inform the development of a framework of PELOS in other locations.

3.1. Interdependencies

Interdependencies refer to the dependence of some infrastructure services on other services to be operational – for example, a water pumping station will require electricity to function, and road access for staff to maintain and, if required, carry out repairs. Various texts identify the complexity of analyzing infrastructure interdependencies in detail, for example Moore et al. [30], Oster et al. [31] and Macaulay [32]. For the creation of the operationalized framework, an exhaustive interdependency analysis was not carried out for this framework due to time and resource constraints, however key interdependency issues were captured at a high level. For example, fuel distribution could only be carried out once roads were open, the water network could not fully operate until power was supplied to pumping stations (using a networked power supply or using fuelled generators) and supermarkets could only take

payment (through the use of credit/debit cards) once they were connected to the telecommunications network (for banking connectivity). One (infrastructure entity) interviewee put it this way: “... our levels of service are somewhat irrelevant if they don’t align with other service providers” (interview 15). Another critical infrastructure entity interviewee noted the reliance on road access:

“... looking at Christchurch, looking at other events that have happened in between, the biggest thing for us is going to be to get access to the sites. So, we could say we’re going to get within two weeks to get things up and running, but if we’re not going to get access, we’d be struggling” (interview 19).

During the interviews, the subject of interdependencies was discussed specifically by ten of the interviewees, spread across the council, CDEM and critical infrastructure entities. Of those interviewees, 18 of the comments received referred to their own sectors, while 19 comments referred to others. This shows that interviewees were comfortable talking of other sectors, and reflects the nature of interdependencies, where some PELOS are only achievable where a preceding service is provided, for example supply of fuel (energy sector) on roads (transport sector) to service stations.

The above high-level approach on interdependencies was taken for two reasons. Firstly, if the logic of interdependencies within the framework (as per the examples above) was correct, then conceptually, the delivery of key services should be achievable. For the Wellington example, detailed analysis, taking into account interdependencies had already been carried out with outage modelling following a rupture of the Wellington fault [26]. Therefore, a comparison of the PELOS against the research that had already been carried out would provide a firm foundation of interdependency analysis. Secondly, greater analysis would be unlikely to change the sequence of events, or the timeframes given in the operationalized framework of PELOS. Finally, acknowledging that an actual emergency will have many different aspects and complexities, greater analysis of interdependencies may provide greater certainty of modelling, but no greater certainty of actual delivery in an event. In this way, the framework is relatively simple in its approach, but a high-level

approach was considered sufficient. Finally, as one interviewee put it: “None of us think we’ve got it right, exactly right. It is a start on the journey” (interview 11).

3.2. Vulnerable communities

The creation of PELOS, in consultation with the utility providers, will help gain an understanding of the planning (but not guaranteed) infrastructure delivery goals in an emergency. As seen in Mowll et al. [2], these are high-level statements of the provision of services within a timeframe. The general provision of a service does not, however, guarantee that all end-users will be able to benefit from that level of service. For example, the immobile (for reasons of age or disability) may not be able to personally collect 20 L of water from a kilometer away. People with disabilities [8,33,34], big bodied people [35], those with severe mental illness [36], linguistically isolated populations [37] and children [38], amongst other groups, may have difficulties in collecting such quantities of water from such distances.

Sphere deals with this issue by recommending that the vulnerabilities and capacities of a population need to be understood. The Sphere Handbook recommends that such an understanding can be achieved firstly by disaggregating population data (which in New Zealand is currently available from Statistics NZ). This helps understand the proportion of the population that may have difficulties in accessing services. As stated in the Sphere Handbook [8], “Response and preparedness programming should consider the capacities and needs of all persons with disabilities and make deliberate efforts to remove physical, communication and attitudinal barriers to their access and participation.” Interviewee 05 put it this way:

“... if I could understand the demographics of the City then I can understand what each... suburb or part of the City, what the demands on them might be for these services and provisions, and I can test and adjust accordingly, depending on how resilient a particular area might be versus another one”.

Therefore, the operationalized PELOS framework, and its companion mapping tool, will provide information on where emergency managers, community groups and groups with disabilities or special needs could best enable participation in planning for an event. The goal would be to organize the assistance that such people may require, in an event. Such planning will be an onerous task, however, can be more targeted in that deliveries of services will be better understood through the identification of PELOS and understanding where vulnerable groups may be located or concentrated. Additionally, representatives of community groups may be invited into the process of emergency planning and establishing PELOS (example Mowll et al. [39]).

3.3. Emergency planning considerations

3.3.1. Considerations for key stakeholders

As outlined in the introduction, there are three sets of parties that are relevant to this framework – the critical infrastructure entities, the emergency management sector, and the end-users. Each will be discussed in turn.

Critical infrastructure entities that sell infrastructure services do not guarantee access to their services. For example, the New Zealand Consumer Guarantees Act [40, Section 7A] states that “when determining what a reasonable consumer would expect, it is assumed that the consumer has considered... that the supply of gas or electricity may be affected by emergencies...”. In other words, customers should anticipate that there will be outages to services in emergency events. As a counter to this, the responsibilities of the critical infrastructure entities under the current (as of April 2022) Civil Defence Emergency Management Act No 33 [22], Section 60, is to “ensure that it is able to function to the fullest possible extent, even though this may be at a reduced level, during and after an emergency”. What the ‘fullest possible extent’ is, is

not elaborated on, and is therefore difficult to establish or measure. The creation of PELOS would therefore create a measurable planning target.

It would be counter-productive to expect the measurement of PELOS post-event to see if goals were achieved. One interviewee noted: “is there an expectation that we’re held accountable for it? We just need to be careful that from an agency, and certainly from a local authority perspective, that they understand the context in which it could be applied” (interview 07). This is the purpose of including the word ‘planning’ in the concept of PELOS. It is a planning tool, not a guarantee of delivery.

If, as noted in Section 1.2 the concept of PELOS is brought into an updated Emergency Management Act, critical infrastructure entities would have to publicly state PELOS, to enable end-users understand what the planning goal for delivery is. Knowing their PELOS, the intention of this framework is that the relevant critical infrastructure entities will then plan for the delivery of that PELOS, in the knowledge of their, and their consultants’ and contractors’, capacities. Further, knowing both the vulnerabilities and redundancies of their respective networks, they will have a better understanding of what resources such as machinery, skilled personnel and fuel will be required to deliver, and where (in both location and type of activities) they will have to place resource for an emergency response.

The Emergency Management sector has a function to “respond to and manage the adverse effects of emergencies in its area” and to “plan and carry out recovery activities” [22, Section 17]. Such activities could include understanding the potential impacts to communities from emergency events, as carried out by the Wellington Lifelines Group [26]. While the Emergency Management sector can make broad assumptions about the delivery of services following an event, the understanding of the intentions of the critical infrastructure entities through PELOS would help in planning, as “... there’s no two ways about it. There needs to be a master plan of some description, that people can pull out, dust off, if not live with, to have a degree of understanding” (interview 14). The knowledge of PELOS will therefore aid the Emergency Management sector to carry out their function of planning activities and respond to adverse events. As noted by Interviewee 04:

“... for emergency management to look to how we fill that gap in the meantime, both from a community point of view, in terms of preparedness, expectation management, that sort of thing, but also for official support, if we need to do that, how do we fill that gap?”

The setting of PELOS in a framework, throughout a region would help in the creation of such a ‘master plan’. As outlined in Section 3.2, the community end-users are not a homogenous group, with a range of abilities to interface with the PELOS, particularly following an emergency event, where some will be located close to services such as emergency water distribution points, and some will be further from them. This dynamic is key information for the emergency management sector, who will be informed by where there may be concentrations of more vulnerable people, and therefore a group (amongst others) that may require targeted assistance.

Another set of end-users includes medical centers and pharmacies. Such facilities will most likely be experiencing very high demand in an emergency event, particularly where easy access to the hospital is not available, as the roading PELOS indicates for days 0–7 after the event. By this phase of the response, however, the medical practices and pharmacies should already have their own generators and fuel supplies to continue to function. Without such services, not only will treatment be impaired but access to key medications that require refrigeration (such as insulin) would be impacted. Due to the modelled outages on the road network, medical centers and pharmacies should have alternative power supplies installed and available pre-event. The operationalized PELOS framework can therefore be a tool to highlight such (inter)dependencies and potential outages. The communication of the contents of the PELOS framework would be necessary to make those end-users aware of the intentions of the critical infrastructure entities.

3.3.2. Choosing a hazard event is critical

The development of the PELOS for the Wellington region has been carried out on the use of a single hazard scenario, the rupture of the Wellington fault. There is a breadth of literature on scenario planning, defined by Porter [41] as ‘an internally consistent view of what the future might turn out to be... not a forecast but one possible future structure’. The intention being that by creating and analyzing a series of scenarios a preferred course of action may be identified and taken. The pitfalls of using a single scenario as a basis for planning and action are highlighted by a range of authors [42–44]. While this is correct, in the absence of a range of modelled scenarios, the creation of the operationalized framework used one scenario as representative of a ‘worst case scenario’ for an earthquake hazard. Much research and emergency management planning in the Wellington region, for example the Wellington Earthquake National Initial Response Plan (National Emergency Management Agency, 2018), has been made 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).

As outlined in Section 2.3.2, the hazard chosen for this operationalized PELOS framework was a ‘major regional event’ but using a rupture of the Wellington fault as a baseline 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. This includes both primary (i.e. shaking) and secondary (i.e. landslides or liquefaction) impacts. The PELOS in the framework, for example the delivery of 15–20 L 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. 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.

At the suggestion of the Advisory Group for this project, the title of the operationalized framework was updated to include the words ‘for a major regional hazard event’ to make it explicit that the PELOS presented in the framework are relevant 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.”

The addition of the words ‘major event’ to the title of the framework makes it clear that the framework is intended to be used for such major scenarios, although the PELOS may still be relevant to some aspects of lesser-scale events, where infrastructure outages from those events extend beyond seven days.

None of the above is intended to replace the need to design individual facilities and structures to the relevant building codes, which will require the adherence to specific magnitudes of hazard events. Rather, as above, the setting of PELOS allows key stakeholders a magnitude of event to understand the scale of potential impact, then match a (in this case single) hazard against their nominated PELOS.

Further, through the above, when nominating PELOS it is not necessary to analyze each PELOS against different hazards, however once the PELOS are complete and agreed, analysis could subsequently be carried out on whether the PELOS will be achievable from individual hazard events. Such analysis could then also consider multi-hazard events and the interdependencies between critical infrastructure sectors.

3.4. Willingness of key stakeholders to collaborate on this work

Much of the key engagement on this research/project has been with the critical infrastructure entities themselves. They know their networks well, the organizational and regulatory context in which they operate and, from their own work 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 their own professionalism and the ongoing risk reduction and readiness work of WeLG and WREMO. Building up such working relationships takes time (WeLG has been working on such issues since 1993) but can be seen to reap rewards in good engagement between relevant organizations, across infrastructure sectors. The creation of an operationalized PELOS framework has been seen by the lead author as a challenging initiative, as it requires organizations to be open about the relative vulnerabilities of their infrastructure. The benefit of having an organizational structure (a lifelines group) in which to facilitate such discussions has been a major benefit to the Wellington region.

As a rough guide to the effort required to create the operationalized 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 has also required the time of the interviewees and management overview input at WREMO, however as a whole need not be an overly onerous task for other organizations or regions to conduct, particularly with the example PELOS framework presented in this paper which could be used as a starting point.

As outlined in Section 2.1, this research was carried out as both research and as a WeLG/WREMO project. The collaboration of the various member organizations of WeLG and of WREMO and other key organizations’ staff was essential for its success, as noted by Interviewee 04: “I think [this project] really builds on the work that’s been done within the region up to now”. The model of ‘lifelines groups’ in the regions of New Zealand has been in practice since the 1990s, and is given a mandate and structure, as detailed by the National Emergency Management Agency [45]. This structure has provided a collaborative space for critical infrastructure entities to share information on long-term risk reduction efforts, as many risk reduction activities cannot be carried out within a single organization or sector, due to the need to take interdependencies into account. In the Wellington region, collaboration has been further enhanced through the successful implementation of projects first outlining the vulnerabilities of infrastructure in the region to the earthquake hazard [24,25] and then promoting a programme of works to reduce risk [26]. The successes of those projects have led to a well-functioning group of organizations having a clear objective – risk reduction to infrastructure in the Wellington region. The research and project carried out on PELOS has only been possible due to this high level of collaboration between parties and through working relationships that have lasted over the 30 years of WeLG’s existence.

Despite the above, there are clear differences in the motivations and dynamics of participation in this research and project of the various stakeholders. Looking across the four critical infrastructure sectors of, energy, telecommunications, transport, and water, it was seen that there were a variety of attitudes to the research and project. The water infrastructure in New Zealand for urban areas is owned and operated by local government [46]. For six of the councils in the region (five of which are within the WeLG area), the management of their water networks has been passed to Wellington Water [47]. Wellington Water adopted a PELOS (20 L of water, per person, per day, within 1 km of the house, from ‘day 8’) [9] in 2018, and having already publicly stated a PELOS and having based its emergency response on the concept, was thus supportive of the PELOS approach, and was happy to confirm the use of the above level of service in the PELOS framework.

Transport infrastructure assets in the Wellington region are largely owned by either central or local government. The Central Government-

owned transport infrastructure providers are Crown Entities or State-Owned Enterprises. Local Government-owned transport infrastructure includes local roads and the regional port. Additionally, the region's international airport is part-owned by a local council. As (most of the above) are governmental organizations, they tend to be managed in the public interest. As such, collaboration with each of these agencies was carried out, in the lead-author's view, as being for the 'public good'. This meant that discussions on the resilience of infrastructure could be carried out in an open way, recognizing that resilience is just one factor of infrastructure management that the owning organization's may consider.

In the energy sector, the power transmission company is a State-Owned Enterprise (Central Government owned) and owns and operates the electricity (high capacity) transmission lines. The lower-capacity distribution networks in the region are owned and operated by companies in their respective areas, one of which is community owned and two of which are privately owned. As the transmission and distribution lines companies run electricity networks in areas as monopolies, they are subject to the regulations managed by the Commerce Commission New Zealand [48]. As such, they cannot make commitments on price or quality of delivery of services without the agreement/approval of the Commerce Commission. This means that detailed discussions between WeLG and the lines companies on any aspect of the supply (including PELOS) must be measured against what is possible within the existing regulatory framework. The gas distribution companies are similarly regulated. This dynamic demonstrates why interacting, where possible, both with the critical infrastructure entities, but also with Central Government agencies is necessary to gain a full picture of dynamics around PELOS.

Relatively, the telecommunications sector is the most complicated sector, both in terms of physical networks and organizational make-up. There are 82 telecommunications and broadcasting network operators in New Zealand, as of April 2022 [49]. Both long-distance and local access fiber optic services are provided by several providers. When making a phone call from a phone on one cellular phone network to another, the services of at least two telecommunications providers will be used (the respective cellular phone operators, plus at least one fiber optic network provider) along with the use of facilities such as exchanges located around the country. Each of the facilities, including any intervening cabinets, must have power to operate. Such interconnectivity leads to difficulties in defining PELOS for single providers. Therefore, the PELOS for the telecommunications sector are deliberately higher-level and non-specific to individual providers.

As can be seen from the above, each sector of infrastructure has a different organizational set-up and different dynamics in terms of being able to engage in discussions on PELOS. This made the creation of a holistic framework covering all sectors challenging, however with the base of transport being an enabler for other sectors (see Section 3.1), once PELOS were defined for transport the definition of PELOS in other sectors became easier. Further, as seen above, the collaboration already in existence at WeLG meant that all stakeholders were happy to engage in the project.

3.5. Flexibility/adaptability of delivery of services

The wording used in the operationalized PELOS framework is, largely, deliberately focussed on the services provided to the end-users, rather than the inputs: "having a clear framework for what 'good' looks like in this space should be a helpful planning tool" (Interview 01). For example, '15–20 L of water, per person, per day, within 1 km of the house, is a key PELOS (for 'the rest of the first month: basic functionality'). The PELOS is not prescriptive of how this is achieved, as it could be carried out through the nearby storage of water (for example, as held in seismically resilient reservoirs), through the sourcing of water from nearby bores or streams (for example as planned to be delivered by Wellington Water [9]), through the trucking of water from outside of the impacted area to the end-users or through the on-site storage of water

by end-users (for example through the collection and storage of rainwater). This allows the critical infrastructure entity to plan for a response not necessarily with business-as-usual delivery methods (in this water example through a reticulated water network) but by other means (for Wellington Water, as above, through storage in resilient reservoirs and sourcing from nearby bores and streams, supplemented by end-users' storage). Similarly, the delivery of electricity may be through an existing (or repaired) network using a distant generation plant, transmission, and distribution lines, or as arranged by end-users (solar panels and batteries, or standby generators with fuel stocks). These approaches are supported by Kartez and Lindell [50] and Alexander [51], who note that emergency plans should allow for flexibility in the delivery of the plan's deliverables.

As above, the wording of the PELOS is intended to enable such flexibility and adaptability in the delivery of services and allows for such flexibility in planning for the delivery of the service, not necessarily the delivery of the same infrastructure to provide the service that was in place before the emergency event. While this is possible for the delivery of water and electricity, this is not possible for other sectors. In the Wellington region, due to the topography of the region, it would not be possible to re-site at short notice in an emergency either the port or airport, or as Interviewee 15 put it "...do not make it so broad and flexible that it could be anything". Therefore, the PELOS for those services are assumed to be using the existing infrastructure, i.e. for the airport, 'operate a 1200 m long runway', at the existing airport location and for the port, the PELOS for the second and third months refers to the availabilities of the berth, jetty and approach structure for fuel delivery.

The road network in the Wellington region is a mix of roads that have been designed and built to be relatively quickly available following a major hazard event such as an earthquake, for example the new Te Ara Nui o Te Rangihaeata road (formerly called the Transmission Gully Motorway) [52], roads that have been assessed to be likely available following a major earthquake, for example Fergusson Drive in the Hutt Valley [25]. For this reason, the PELOS for roads acknowledges that priority roads (priorities 1 to 4) 'or alternates' should be used to deliver the services. This is not a guarantee of service following an event, as the nature of the event will be different to that modelled or used for assessments by geotechnical engineers, but is a guide for what may, or may not, be available following an event, with implications for restoration times, hence the caveats on the delivery of service given immediately below the operationalized PELOS framework.

4. Discussion points and engagement issues

From a practical standpoint, there were various aspects that were important in the creation of the framework, both from the perspective of the facilitator / researcher, and from the perspectives of the key stakeholders.

4.1. Implications of the themes

The themes developed above, of interdependencies, vulnerable communities, emergency planning considerations, willingness to collaborate on this work, and flexibility/adaptability of the delivery of services, all have implications for the task of creating PELOS frameworks. For the creation of the operationalized paper, all these aspects demonstrate that the task of creating PELOS is, to some extent, subjective. For example, as highlighted in the 'vulnerable communities' theme (Section 3.2), the distance between supermarket and dwelling would be unachievable for some members of the community, as they are too old, too young to walk or cycle to a supermarket, or otherwise unable to interface with the PELOS. While subjective, the creation of PELOS is a starting point for discussion. This leads to the considerations in the remainder of this section.

4.2. Who should lead the creation of a PELOS framework?

One of the key aspects of the PELOS framework is that it is holistic, across infrastructure sectors. While PELOS could be created for a single sector or infrastructure such as electricity distribution supply, they would most likely lack the interdependency factors such as access to fuel (for generators for alternative power) and road access (to deliver fuel and to repair damaged electricity lines). The framework is therefore greatly enhanced by the all-sectors approach, which considers interdependencies (at a high level) and the delivery of key infrastructure services needed to help a region both respond and take initial steps towards recovery from a major emergency event.

If such a framework is required to cover the energy, telecommunications, transport and water sectors, some form of engagement mechanism or facilitation is required between the sectors. The work of both WeLG and WREMO as established regional organizations to carry out this facilitation has been critical to enable this process. If it were not for either of these organisations, it is not clear to the authors which would be the best organization to lead such work. While Central Government Ministries could take the lead on such work, they tend to be focussed on single issues (transport, energy, water) or lack the mandate to carry out regional or local planning, where, for example, local councils have the mandate. The collaboration and facilitation enabled through the regional lifelines group and emergency management organization has therefore suited this work well.

In addition to the existence of WeLG and Wellington Region CDEM Group, the governance and leadership of WeLG and WREMO has also been a key factor. Both include experienced politicians (the Chair of WeLG and the Governance of the CDEM Group, which effectively comprises the mayors of the region). This support has provided excellent guidance prior to, and during, the delivery of the project/research and has flowed on to support at key decision points. The issue of who should lead the creation of the framework is therefore not a factor of scale, rather of co-ordination across interdependent sectors.

4.3. Publicly release framework?

When asked whether it would be acceptable to stakeholders to publicly release the operationalized framework, as would be carried out through the publication of this paper in an academic journal, or as a proactive action by WeLG or WREMO, at the time of the interviews, of the 29 opinions expressed, 27 stated they were happy with the public release and two stated that further work needed to be done prior to releasing the framework. Both of these interviewees work for critical infrastructure providers, and both needed, at the time of the interview, to check back with their senior managers and Boards. For many of the interviewees, there was a desire that there should not be a linkage between a framework for PELOS and a commitment to achieving the PELOS should an event happen 'tomorrow'. This is particularly relevant where past reports released by WeLG (Wellington Lifelines Group, 2012, 2013, 2019) 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 operationalized framework. To mitigate the infrastructure providers' concerns, it was agreed that caveats and assumptions should be included with the operationalized framework that "end-user experience may vary" in the delivery of services, indicating that not all PELOS will be achievable following an event, in all locations, and that information on the PELOS should also point towards where they are currently known not to be achievable. Additionally, the framework is not intended to imply any commitment by the various stakeholders at the time of the interviews, instead they are intended to be tool for planning purposes only. More than one interviewee thought that a better approach would be to calculate the cost of delivery of all PELOS prior to public release of the framework, so

that costs and PELOS could be matched for a potential public consultation. These issues were discussed at the group workshop, at which it was agreed that the framework could be published in a journal (this paper) if it was made clear that the PELOS are goals for delivery, not commitments to achieve a particular level of service in an as-yet-unknown future emergency.

4.4. End-user expectations

Information on potential outages to infrastructure services from a major emergency event had previously been published by WeLG and WREMO (as detailed in Section 1.1). While this would provide good planning information for end-users in the Wellington region, for example giving ideas on how long it would take to restore road access or power supplies, the impacts to end-users were not necessarily made explicitly clear, such as the time to restore supply to a local supermarket or the impact of power outages, there was little information available on what such infrastructure outages would mean for the end-users. The mapping created for this project will further enhance that understanding by providing information on what the outages mean for the end-users. This will help the end-users plan for such outages, for example for emergency water and food storage and to make plans for how to respond in such an event.

It should also be noted that, when referring to potential infrastructure outages, the critical infrastructure entities will, on the whole, only be able to comment on outages to their infrastructure networks, and not to indirect impacts, such as collapsed buildings on roads, or loss of power on other networks. This is a distinction that may be made at the time of release of any modelled infrastructure outages.

4.5. Was the action research methodology appropriate for this work?

Section 2.1 details the reasons for adopting the Action Research methodology for this research. This was seen, by the authors, to be an ideal means of carrying out this research. It allowed, as anticipated, for a practitioner (the lead author) to engage within his organizations (WeLG and WREMO) and with related stakeholders on a concept requiring a theoretical foundation. Drawing together the academic and industry sectors was an approach that produced new learnings for the academic sector and further developed a working concept for the practitioners.

4.6. Would these PELOS be applicable universally?

Of the PELOS in the preliminary and operationalized frameworks, the only PELOS that is robustly grounded in literature and experience is the water PELOS 'for the rest of the first month': "15–20 L of water per person per day within 1 km of the house". All other PELOS in the preliminary and operationalized framework are guided, where available, by literature, however many of the PELOS have simply been created through discussion at the research/project interviews. As such, most of the PELOS have been created for the context (topography, hazard-scape, organizational set-up, governmental structures) of the Wellington region. Despite this, there are some PELOS that may be adapted to other regions of New Zealand, or internationally. For example, the PELOS for the airport references the availability of runway lengths appropriate for landing and taking-off turboprop and jet passenger aircraft. While the timeframes for such PELOS may differ in other regions (i.e., by the end of the first week, or by the start of month 4), the PELOS themselves may be adoptable in other regions. Therefore, the wording of the PELOS may be translatable to other regions while the timeframes may alter. Alternatively, each region may consider their own PELOS in conjunction with their key stakeholders, who would need to engage with their own regulatory bodies in such discussions.

4.7. Limitations of the research

The following limitations of the research must be acknowledged. Firstly, using the action research methodology has been followed, putting in place the necessary processes to minimize bias in research. However, despite such efforts, the interviewer and interviewee, in most cases, had been working together on emergency management issues for up to a decade. This means that shared knowledge and understandings of emergency management issues may have led to short-cuts of discussion. While this is seen as a potential shortfall, it may also be an advantage to the research, in that it minimized the need to explain, or discuss, aspects of emergency management at the times of the interviews.

This research has focussed on a single ‘moderate or large scale’ hazard. While the evidence provided by WeLG reports, and the opinions of the interviewees has supported this approach, there would be advantages in, at a later date, extending the comparison of the PELOS framework to other hazards such as distant-source tsunami or large-scale flooding, hazards listed in the WREMO Group Plan [27]. This may be possible in time, if research is conducted to understand the impacts of such hazard events. While this would provide greater information, as discussed in Section 2.3.2, this approach may not, in any case, change the PELOS identified in the operationalized framework. It would, however, allow key stakeholders to know the scenarios in which the PELOS may not be achievable in a response.

While there was effectively blanket coverage of organizations interviewed, there was potential to gain further opinions from each organization, however time constraints prohibited interviewing more participants. In any case, at least one person from each of the key critical infrastructure entities was interviewed, in all cases those people being experienced professionals from their respective sectors.

5. Conclusions

As above, the approach to creating a framework of PELOS for the region has been explained, alongside a case study from the Wellington region of the creation of a framework. Key themes were explored that were features of the process which will be of interest to anyone creating a similar framework for other locations.

Having a robust understanding of the hazardscape in the region has been essential for the creation of this operationalized PELOS framework. All of the infrastructure outage studies carried out by WeLG and WREMO [24–26] were, in turn, informed by the work of GNS Science in the ‘It’s Our Fault’ project [53], which provided understandings of the earthquake hazard in the region (for example, fault locations, liquefaction potential, lateral spreading and co-seismic subsidence susceptibilities and landslip dynamics) and, in turn, modelled outages [26]. Without such detailed information, timeframes for outages would be less informed and the general hazard-scape of the region would be less understood. The significance of this strong foundation to all subsequent projects and analysis is hard to overstate. While the creation of a PELOS framework would be possible without such a foundation, it would be less informed and may need to be more generic in its approach to cover many potential infrastructure outage possibilities.

The collaboration of the critical infrastructure entities and the emergency management sector has been essential in the creation of the operationalized PELOS framework. Indeed, the creation of the operationalized framework would not have been possible without them. The vehicle of the Wellington Lifelines Group has been very effective as an organizational structure to facilitate the creation of the framework.

The theme of interdependencies acknowledges that this framework only addresses interdependency issues at a relatively high level, noting that following research/project work will map the achievability of the PELOS in the operationalized framework against previous work [26] that has carried out a rigorous interdependency analysis.

The PELOS in this framework helps identify issues around the vulnerability of some segments of the community, for example those unable to collect water from up to 1 km or food from distances of up to 2 km. This is a feature of the framework that better informs emergency planning efforts, highlighting the work that is required to support such community members.

This research/project has demonstrated that it is possible to create an operationalised framework of PELOS across infrastructure sectors. As noted by Interviewee 16:

“uncharitably, [the PELOS concept] will be put up for target practice and you know, there’ll be people pointing out, you know, the errors of the thinking and this, that and the next thing, which is the whole point, right. The exercise is to fill gaps in current thinking and logic” (interview 16).

This work is now available for scrutiny by the academic and infrastructure communities, however, may be seen as an advancement in the Wellington region’s collective understanding of planning for and responding to major emergency events. This has the potential to inform not just the critical infrastructure entities and emergency management sector on outages and informing each other (across infrastructure sectors and to emergency management), but also the end-users of outages. This will inform potential infrastructure impact mitigation projects, and emergency response plans at the household, suburb (for community groups) and regional level (for emergency management and critical infrastructure entities). In proposing a linkage between infrastructure service provision and community needs, does this make PELOS a silver bullet for understanding this linkage? Or useful for target practice, as a concept that has levels of service that may be considered by some to be arbitrary in nature? The authors believe that, while it may not be a silver bullet, it does provide greater structure in which to consider what infrastructure providers could be planning for in an emergency, and the potentially impacted communities an understanding of what is planned to be provided Fig. 2.

Relevance to resilience statement

The concept of ‘planning emergency levels of service’ is relevant to resilience in that it creates pre-event planning targets for infrastructure providers for the design and construction of their networks and facilities and guides their emergency response planning. If taken forward in conjunction with the emergency management sector, it can also assist in identifying how vulnerable members of the community may best be helped in an emergency to benefit from the response. While not a measure of resilience, if the city or region’s infrastructure providers can provide the full set of planning emergency levels of service, the city or region will be more resilient.

Declaration of Competing Interest

Richard Mowll reports financial support was provided by QuakeCoRE. Richard Mowll reports financial support was provided by National Science Challenge. Richard Mowll reports a relationship with Wellington Lifelines Group that includes: employment.

Acknowledgments

This project was supported by QuakeCoRE, a New Zealand Tertiary Education Commission-funded Center. This is QuakeCoRE publication number 0720. Partial support was also provided by Kia manawaroa – Ngā Ākina o Te Ao Tūroa (Resilience to Nature’s Challenge - National Science Challenge).

The assistance, advice and willingness to participate of all interviewees, and of WeLG members and WREMO to enable this work to proceed has been invaluable. Thank you.

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