

**Infrastructure planning emergency levels of service for the Wellington region, Aotearoa  
New Zealand**

A thesis presented in fulfilment of the requirements for the degree of

Doctor of Philosophy

in

Psychology (Emergency Management)

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## Abstract

Past work has demonstrated that the infrastructure in the Wellington region, Aotearoa New Zealand, is vulnerable to natural hazard events such as earthquake and tsunami. To enable common understandings of the levels of service (or targets) that critical infrastructure entities are planning on delivering in an emergency event, the concept of ‘planning emergency levels of service’ (PELOS) is developed and presented in this thesis. Such a concept is readily relatable to the water sector where, for example, the World Health Organisation’s ‘basic access’ to water standard is for ‘20 litres of water, per person, per day, within 1km of the dwelling’. Despite such standards for water, there are few other examples in the sectors of energy, telecommunications and transport. A literature review investigated relevant sources of information on the concept from both academic and from infrastructure sector-specific texts and was used in developing a preliminary framework of PELOS, alongside discussions with emergency management experts in the Wellington region. The overall PELOS concept and preliminary framework was then presented in interviews and workshops with key stakeholders, and qualitative data collected from these interactions was used to create an ‘operationalised’ PELOS framework. This framework was adopted by the Wellington Lifelines Group, a grouping of the critical infrastructure entities in the region. Key themes of the PELOS concept are explored, namely: interdependencies, the need to consider the vulnerabilities of some community members, emergency planning considerations, stakeholders’ willingness to collaborate and the flexibility/adaptability of the delivery of infrastructure services following a major event. Further, a description of the process taken to develop the framework is provided to enable other regions to create their own frameworks. A mapping tool, visualising where PELOS can, and cannot, be achieved based on hazard impact modelling is presented. This allows the infrastructure entities, the impacted communities and the emergency management sector to have a common understanding of the targets of response following a major hazard event, and plan for them in future.

## Impact statement

A framework and mapping tool for ‘planning emergency levels of service’ (PELOS) for the Wellington region, Aotearoa New Zealand was developed, showing how the infrastructure utilities will deliver services following a major earthquake. These can help the community understand what they should plan for in such an event. They can also help the utilities and emergency management sector plan for major events.

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## List of tables

Table 1: The author’s alignment with different research paradigms using the HARP tool .....	25
Table 2: Research philosophies - overview (adapted from Saunders et al (2016, pp.136-137).....	26
Table 3: Overview of steps to be taken in this research, in alignment with action research philosophy .....	33
Table 4: Demographics of interviewees (Total participants = 30).....	41
Table 5: Demographics of focus group (Total participants = 7) .....	42
Table 6: Stages to update the preliminary framework to the operationalised framework.....	43
Table 7: Demographics of mapping tool workshop (total participants = 8) .....	45
Table 8: Summary of water emergency storage and restoration goals.....	58
Table 9: Reasonable walking or cycling distances .....	63
Table 10: Wellington region -planning emergency levels of service - PRELIMINARY FRAMEWORK.....	77
Table 11: Wellington region - infrastructure planning emergency levels of service - OPERATIONALISED FRAMEWORK for a MAJOR REGIONAL HAZARD EVENT .....	92
Table 12: logic for key interdependencies .....	113
Table 13: interviewees - number and sectors .....	131
Table 14: Coding nodes and references captured .....	133
Table 15: Details of the amenity types used within this study and their source.....	163
Table 16: Functionality classifications of amenities and critical infrastructure.....	164
Table 17: Walking distance categories for access to amenities.....	165
Table 18: Emergency sanitation options. The emergency sanitation workshops assessed emergency sanitation options as follows: .....	251

## List of Figures

Figure 1: (A) Tectonic setting of Aotearoa New Zealand; (B) Known active faults in central Aotearoa New Zealand, with the Wellington Fault shown in red (from Stewart, Johnston, Kim, & Nayerloo, 2016) ..	15
Figure 2: Grix's interrelationship between building blocks of research. Source Grix, 2002, modified from Hay (2002). .....	24
Figure 3: Local councils comprising the Greater Wellington region, New Zealand.....	49
Figure 4: Local councils comprising the Wellington region, Aotearoa New Zealand .....	86
Figure 5: Local councils comprising the Wellington region, Aotearoa New Zealand .....	124
Figure 6: PELOS creation process diagram .....	127
Figure 7: PELOS mapping tool creation process. Part-reproduced from Mowll et al. (2023a) .....	158
Figure 8: Functionalities of the 'for planners' site section .....	168
Figure 9: Electricity level of service over time. Region-wide view demonstrating the ability for facilities and homes to access power. A) 0-7 Days. B) 8-30 Days. C) 31-90 Days. D) 90+ Days. Red describes that the service is non-functional; Orange/Yellow is partial functionality; Green is >80% functionality.....	169
Figure 10: Accessibility to food sources over time. shows how access to supermarkets changes over four time periods post-event: 0-7 days, 7-14 days, 15-30 days, and 31-90 days. Figure 4(a) shows the total loss of access to supermarkets (due to loss of road access between distribution centre and the supermarket, meaning that re-stocking is not possible by road), demonstrating why residents throughout the region should store enough food supplies for their household for the first seven days post event (as highlighted in WREMO’s household preparedness resources (Wellington Region Emergency Management Office, n.d.-f)).....	170
Figure 11: Option for residents to explore what their levels of service are over time based on their address .....	172
Figure 12: The Wellington region, Aotearoa New Zealand. Source: Wellington Region Emergency Management Office.....	247
Figure 13: The sanitation chain. Source: Wirmer (2014) .....	250
Figure 14: 'Don't Flush' infographic.....	253

# Contents

List of tables.....	6
List of Figures .....	6
Contents .....	7
1 Introduction.....	13
1.1 Context and definitions .....	13
1.2 The researcher’s position and journey with ‘PELOS’ .....	17
1.3 Research problem.....	18
1.3.1 Summary of existing literature.....	18
1.3.2 Gaps in the existing research .....	20
1.4 Research questions .....	20
2 Research position, methodology, and positionality .....	22
2.1 Alignment between this research and the researcher’s work with the lifeline utilities 22	
2.2 Ontological and epistemological positions .....	23
2.2.1 Ontology .....	25
2.2.2 Epistemology and research strategy.....	28
2.2.3 Values and motives .....	30
3 Research methods .....	32
3.1 Research strategy.....	32
3.2 Characteristics of qualitative research and why it is appropriate here .....	34
3.3 Data collection.....	34
3.3.1 Ethics approval.....	34
3.3.2 Interviews and workshops.....	35
3.4 Research process in detail .....	37
3.4.1 Paper 1: Literature review and creation of a preliminary framework.....	37
3.4.2 Paper 2: based on research, present an operationalised (updated) framework (qualitative research).....	38
3.4.3 Paper 3: ‘How to’ create a PELOS framework .....	43
3.4.4 Paper 4: A new mapping tool to visualise critical infrastructure levels of service following a major earthquake .....	44
4 Paper 1: Infrastructure planning emergency levels of service for the Wellington region, Aotearoa New Zealand – a preliminary framework .....	46
4.1 Authors .....	46
4.2 Abstract .....	47
4.3 Introduction .....	47

4.4	Wellington region context .....	49
4.5	Methodology .....	50
4.5.1	Literature review methodology .....	50
4.5.2	Framework creation methodology .....	51
4.6	Wider issues regarding the setting of ‘emergency LoS’ .....	52
4.6.1	Wider issues regarding the setting of ‘emergency LoS’ .....	52
4.7	Deriving preliminary framework and LoS .....	55
4.7.1	Water .....	56
4.7.2	Road access .....	60
4.7.3	Fast Moving Consumer Goods (FMCGs) (for food) .....	66
4.7.4	Fuel .....	68
4.7.5	Power (electricity) .....	69
4.7.6	Telecommunications and broadcasting .....	71
4.7.7	Sanitation .....	73
4.7.8	Shelter .....	76
4.8	The overall framework .....	76
4.9	Assumptions, caveats and limitations .....	79
4.9.1	Key assumptions and caveats .....	79
4.9.2	Limitations .....	80
4.10	Discussion and conclusions .....	80
5	Paper 2: Infrastructure planning emergency levels of service for the Wellington region, Aotearoa New Zealand – an operationalised framework .....	83
5.1	Authors .....	83
5.2	Abstract .....	84
5.3	Introduction .....	84
5.4	Methodology .....	87
5.4.1	Preliminary work .....	87
5.4.2	CDEM Act (2002) Update .....	88
5.4.3	Interviews and Focus Groups (and Analysis) .....	88
5.4.4	Final Consultation and Decision Making .....	90
5.5	Operationalised framework .....	90
5.6	Results – general issues .....	95
5.6.1	Usefulness of the framework .....	95
5.6.2	Availabilities of other frameworks .....	96
5.6.3	Public release of the framework? .....	96

5.6.4	Hazard event for the framework .....	97
5.6.5	Timeframes (one week, one month, three months and beyond) .....	97
5.6.6	Other services.....	99
5.7	Results – sector-specific results .....	99
5.7.1	Water .....	100
5.7.2	Road access.....	101
5.7.3	Fast Moving Consumer Goods (FMCGs) (and Liquefied Petroleum Gas (LPG)) 102	
5.7.4	Fuel .....	103
5.7.5	Power (electricity).....	104
5.7.6	Telecommunications and broadcast .....	105
5.7.7	Sanitation .....	107
5.7.8	Shelter .....	108
5.7.9	Port.....	108
5.7.10	Airport.....	110
5.7.11	Gas .....	111
5.8	Interdependencies.....	112
5.9	Discussion .....	114
5.9.1	Operationalising the framework .....	114
5.9.2	Relationship between PELOS and a hazard event.....	115
5.9.3	Engagement with the critical infrastructure entities has been key.....	116
5.9.4	Future research required .....	117
5.10	Conclusion.....	117
	Acknowledgements.....	118
6	Paper 3: Creating a ‘Planning Emergency Levels of Service’ framework – a silver bullet, or something useful for target practice?.....	119
6.1	Authors .....	119
6.2	Abstract .....	120
6.3	Introduction .....	120
6.3.1	Planning Emergency Level of Service (PELOS) overview .....	120
6.3.2	The Wellington Region Context .....	123
6.4	Creating a PELOS framework: methodology and process.....	125
6.4.1	Research philosophy .....	125
6.4.2	Process taken to create the PELOS framework .....	126
6.4.3	Preliminary work .....	128

6.4.4	Interviews and focus groups .....	130
6.4.5	Decision-making and finalisation .....	134
6.5	Key themes and issues: .....	135
6.5.1	Interdependencies .....	135
6.5.2	Vulnerable communities .....	137
6.5.3	Emergency planning considerations .....	138
6.5.4	Willingness of key stakeholders to collaborate on this work.....	142
6.5.5	Flexibility/adaptability of delivery of services .....	145
6.6	Discussion points and engagement issues .....	146
6.6.1	Implications of the themes .....	146
6.6.2	Who should lead the creation of a PELOS framework? .....	147
6.6.3	Publicly release framework?.....	147
6.6.4	End-user expectations .....	148
6.6.5	Was the Action Research methodology appropriate for this work?.....	149
6.6.6	Would these PELOS be applicable universally?.....	149
6.6.7	Limitations of the research.....	150
6.7	Conclusions .....	151
7	A new mapping tool to visualise critical infrastructure levels of service following a major earthquake .....	153
7.1	Authors .....	153
7.2	Abstract .....	154
7.3	Introduction .....	154
7.4	Methodology .....	157
7.4.1	Research context .....	157
7.4.2	Underlying data used in the tool .....	161
7.5	The Tool: An Interactive Dashboard .....	167
7.5.1	Landing page.....	167
7.5.2	'For planners' section.....	167
7.5.3	For public .....	171
7.6	Discussion .....	172
7.6.1	Functionality of the webtool .....	172
7.6.2	Process/approach overview.....	174
7.6.3	Key insights from the webtool.....	174
7.6.4	Limitations .....	175
7.6.5	What have we learnt from this process? .....	177

7.6.6	Applicability to other regions .....	178
7.7	Conclusion.....	178
8	Discussion.....	180
8.1	Context.....	180
8.2	Methodology and methods.....	181
8.3	Revisiting research questions .....	182
8.3.1	Can a framework for emergency levels of service be created... ..	182
8.3.2	‘What is needed to develop a framework...?’ .....	184
8.3.3	‘What planning emergency levels of service could be defined...?’ .....	186
8.4	Limitations .....	187
8.5	Future research suggestions .....	190
8.5.1	Evacuation and adaptation decisions – when would people leave their homes and how would they adapt to infrastructure outages? .....	191
8.5.2	What are the walking distances Wellington residents could manage in an emergency event?.....	192
8.5.3	How quickly does the fuel run out, and how is it re-supplied?.....	192
8.6	Potential replication of a similar framework for other regions of New Zealand, or internationally .....	193
9	Conclusion .....	195
	REFERENCES .....	197
	Appendices.....	208
	Appendix 1: Statement of contribution sheets for submitted journal papers.....	209
	Appendix 2: Ethics notifications.....	213
	Appendix 3: Information sheet: interviews.....	233
	Appendix 4: Participant consent forms: interviews .....	237
	Appendix 5: Structured interviews: questions .....	238
	Appendix 6: Information sheet: workshops .....	240
	Appendix 7: Participant consent forms: workshops .....	244
	Appendix 8: Structured workshop agenda.....	245
	Appendix 9: EXEMPLAR CREATION OF A PLANNING EMERGENCY LEVEL OF SERVICE: Creating a post-earthquake sanitation plan for the Wellington region, Aotearoa New Zealand.....	246
9.1	Authors.....	246
9.2	Abstract .....	246
9.3	Introduction .....	247
9.4	Stakeholder and organisational responsibilities .....	248

9.5	Creating an emergency sanitation plan .....	248
9.5.1	Stakeholder collaboration and engagement .....	249
9.5.2	Goal of the plan and levels of service .....	249
9.5.3	Workshops.....	249
9.6	‘Don’t Flush’ .....	252
9.7	Next steps .....	254
9.7.1	Public education.....	254
9.7.2	Procurement and marketing - a public-private partnership.....	254
9.7.3	Ongoing engagement .....	254
9.8	Conclusion.....	255
Appendix 10: Paper 4, mapping tool – supplementary information .....		256

# 1 Introduction

## 1.1 Context and definitions

To quote Antonio Guterres, the Secretary-General of the United Nations, ‘nothing undermines sustainable development like disasters’ United Nations Office for Disaster Risk Reduction (2022). Of course, more than just development is disrupted, humanitarian impacts of large-scale hazard events can be significant (UNHCR et al., 2002). The Sendai Framework provides a forward-looking framework for disaster risk reduction. The Sendai Framework provides four priorities for reducing disaster risk, two of which are “investing in disaster risk reduction...” and “enhancing disaster preparedness...” (United Nations Office for Disaster Risk Reduction, 2015, p. 14). However, despite clear knowledge of potential disasters in the Wellington region (GNS Science, 2020), the level of preparedness of households in the region could be improved (Blake et al., 2018). This could, partly, be due to the lack of household knowledge of the impacts of major events (Colmar Brunton Ltd., 2018). Further, there is knowledge of what investments could be made in the Wellington region for disaster risk reduction (Wellington Lifelines Group, 2019), however until now there has been little guidance on the emergency functions that the infrastructure entities should be providing to households.

Infrastructure services are such a part of high income economies that sometimes they might be taken for granted, until they are disrupted (Singh, 2020). As noted by Hallegatte et al. (2019, p. 15), ‘making infrastructure more resilient requires a consistent strategy’. They note that systems for response should be created prior to the event through good maintenance and plans for ‘postincident response’. This suggests that providing resilient infrastructure should be considered prior to the event. Emergency management in New Zealand covers the ‘4Rs’ of risk reduction, readiness, response and recovery (National Emergency Management Agency, n.d.-a). The first of these, risk reduction (including both maintenance and the consideration of the robustness of the infrastructure), is a significant component of ‘Disaster Risk Reduction’. The second of these, ‘readiness’ relates to the ‘plans for the postincident response’.

Lifeline utilities are the infrastructure organisations that provide services such as water supply, electricity supply, roads and ports and telecommunications to the community, sometimes referred to as ‘critical infrastructure entities’. In high-income countries we depend on them to deliver our water, food and a whole range of daily needs. As will be seen in this thesis, no

service is ‘guaranteed’, so we need to consider how we will respond (collectively and individually) when there are infrastructure outages. While the infrastructure is not functioning, individuals will still require water, food, power, shelter and health services. In Aotearoa New Zealand the infrastructure organisations are formally listed in the Civil Defence Emergency Management Act No 33 (2002), and often referred to as covering the four sectors of energy, telecommunications, transport, and water. In Section 60 of the Act it states 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.” Without the delivery of such utility services over a prolonged period, such as following a hazard event, the impacted population will be without the necessities for life, including food and water, and with poor access to, for example, healthcare, due to the need to use roads to get to the health facilities. These utility services may be provided in several ways, including through the provision of robust infrastructure or, recognising that infrastructure may be damaged in hazard events, through activating emergency plans or utilising backup or redundant parts of the network. The above statement in the Act is valuable to set expectations, however the wording is vague on the required performance, or ‘level of service’, that should be achieved by lifeline utilities in an emergency.

The term ‘level of service’ is used in this research because it is a commonly used term in infrastructure Asset Management practices, where infrastructure is described by asset condition, performance and other relevant outputs (Edwards, 2010). It is therefore a term that will be well understood by infrastructure providers. If described well, such terms should also be able to be understood by laypersons and the emergency management sector. Adding the word ‘emergency’ shows that this measure is specific to the level of service to be delivered during or following an emergency or disaster event.

The Wellington region, Aotearoa New Zealand was chosen for this research for the following reasons. It presents, as seen above, an interesting case study as it builds on the previous work carried out by GNS Science (It’s Our Fault), the Wellington Lifelines Group and the Wellington Region Emergency Management Office (WREMO). The above work has created the science to understand the risk of earthquake to the region and the nature of the seismic hazard (GNS Science, 2020), modelled outages that could be faced by infrastructure damage following a rupture of the Wellington Fault (Wellington Lifelines Group, 2012, 2019) and has provided a framework for emergency management in the Wellington Region Emergency Management Office (2019). As such, the Wellington region therefore represents not just a foundation of work

to progress from, it also presents a situation with a significant level of complexity to be grappled with. While this research has been carried out for the Wellington region, the research will also consider (Section 8.6) how a similar framework could be created for other regions of New Zealand, or internationally.

There are known vulnerabilities to natural hazards in the various lifeline utilities networks in the Wellington Region. For example, the Wellington region has various fault lines running through it, which various bulk water pipelines, electricity, road and telecommunications networks cross (Figure 1) (Stewart et al., 2016). Major earthquakes impacting the region have included a magnitude 8.2 in 1855, a magnitude 6.8 in 1917 and a magnitude 7.0 in 1942 (Te Taura Matapae Pumate Ru i Aotearoa, 2022). As seen in the Canterbury sequence of earthquakes in 2011, liquefaction and land movements can cause damage to infrastructure, examples at (Massie & Watson; Moratalla & Sadashiva, 2022; Palermo et al., 2011). Other hazards that can impact infrastructure in the Wellington region include tsunami, flooding and storms (Wellington Region Emergency Management Office, 2019).

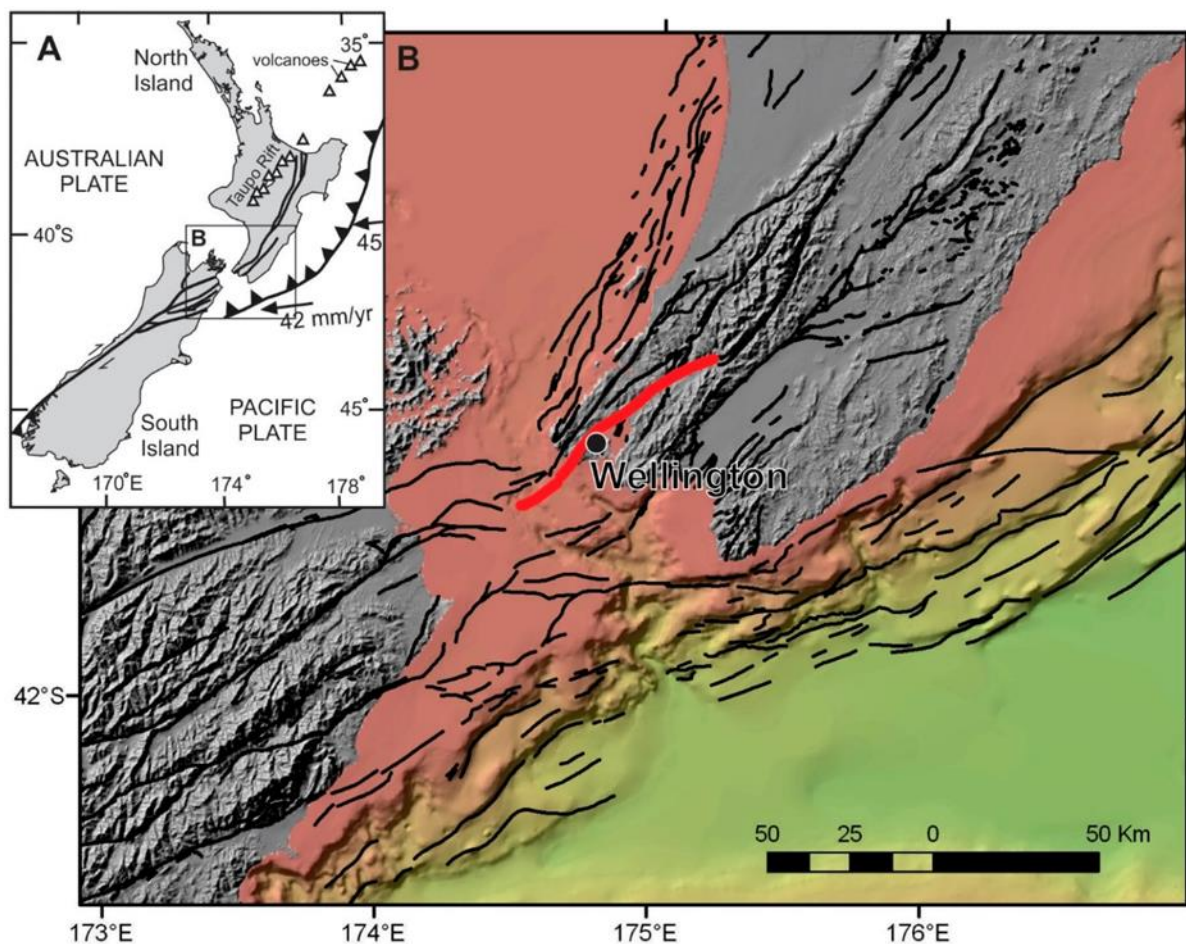


Figure 1: (A) Tectonic setting of Aotearoa New Zealand; (B) Known active faults in central Aotearoa New Zealand, with the Wellington Fault shown in red (from Stewart, Johnston, Kim, & Nayyerloo, 2016)

These vulnerabilities are across the energy, telecommunications, transport (and therefore also food delivery) and water sectors and have been documented in reports such as by the Wellington Lifelines Group (WeLG), which demonstrate the impacts of a major earthquake on the infrastructure in the region. For example it has been estimated through modelling that, following a rupture of the Wellington Fault, the eastern suburbs of Wellington City will be without piped potable, water for six months to a year, and without a cabled power supply for three to six months (Wellington Lifelines Group, 2012, 2019). Other hazards that could impact infrastructure in the Wellington region are documented by the Wellington Region Emergency Management Office (2019) and include tsunami, flooding, pandemic and severe weather. With known hazards, and modelled outages to infrastructure as a result of some of the hazards, it is known that there will be infrastructure outages following some hazard events.

If the household needs of delivery of utility services (or infrastructure emergency levels of service) can be defined, the gap between modelled infrastructure outages and the required levels of service can then be defined at community, or more specifically, at ‘suburb level’ (i.e. levels of service anticipated to be delivered to any particular suburb, as a whole). The suburb level is chosen for representation, as modelling has previously been carried out to the suburb level on hazard impacts on the Wellington region (Wellington Lifelines Group, 2019). For example, if the recommended emergency level of service for water delivery is that water be available by day ‘x’, and the infrastructure provider and the emergency response authorities estimate that it will only be possible to provide water to a particular suburb by day ‘y’ (sometime after day ‘x’), that will be a gap. The identification of gaps aids the lifeline utilities and the emergency management sector to consider potential infrastructure strengthening or alternative means of provision of the utility services, and refine emergency planning for the affected suburbs, reducing the risk and increasing readiness for an event. It is for the critical infrastructure entities to consider strengthening infrastructure and creating emergency responses plans in the case of outages and it is for the emergency management sector to consider how communities will be supported during such outages and refine emergency planning. Similarly, this information would be useful to the communities themselves, setting expectations of service delivery and thus informing personal preparedness actions and detailed local planning.

While other frameworks exist for identifying and measuring ‘resilience’, as will be seen in Section 4.6.1.4, these frameworks do not address the needs of individuals, as most existing

frameworks take a more city-scale approach to measurement. By only measuring at the city-level, individuals may not be able to connect with the proposed levels of service, understanding the direct implications for them. Therefore, there is a need to better understand ways of how identify the utilities' post-disaster levels of services in ways that people can understand and then plan for these.

## 1.2 The researcher's position and journey with 'PELOS'

The researcher holds the following roles in his work as a consultant/contractor. He is the Project Manager of the Wellington Lifelines Group (WeLG), a group that works to 'facilitate discussion, particularly on hazard understanding and risk reduction measures on the Wellington Region's infrastructure' (Wellington Lifelines Group, n.d.). He is also the Lifeline Utilities Co-ordinator for the Wellington region, New Zealand, planning for and responding to emergency events in the Wellington region that have caused damage to utilities that requires co-ordination with the emergency management sector. He has held the above roles since 2011.

In 2001, the author learnt of the year 2000 version of the Sphere Handbook (Sphere Association, 2018). He found this a profoundly simple, but effective, document, based in science (for example, how much water people require in an emergency event), with a simple set of standards (for example, a person requires 15 litres of water, per person, per day, within 500m of the dwelling). This is a measurement that the person requiring water can understand, and it provides the provider (or utility) with a measure of what should be delivered.

In 2013, as the Project Manager of WeLG, he was involved in a project that aimed to define 'emergency levels of service' with the WeLG members. Discussions on the subject made it clear that many people, and organisations, were happy to consider and define their own emergency levels of service, however a proportion would not proceed with the concept. This meant that an overall framework of levels of service could not be delivered at that time due to interdependency issues (other utility sectors could not understand, or plan, their emergency levels of service if they could not see what the other utilities had as their emergency level of service). This was a very instructive project, showing that the subject is, clearly, not embraced by all, however with changes in approach, and a foundation in theory, the concept might be taken forward. As such, and as noted in Section 2.1, it was decided to effectively re-run the

project in 2019, but with a fresh approach. This effectively created the motivation for this thesis.

## 1.3 Research problem

### 1.3.1 Summary of existing literature

A Full literature review is presented in Section 4. To provide context for the methodology and research outline, the following summary is provided.

Frameworks exist for the measurement of infrastructure resilience and for understanding the consequences of hazard events on communities and cities. These include the National Institute of Standards and Technology (NIST) Planning Guide (National Institute of Standards and Technology, 2016) and ISO37123 (International Organization for Standardization, 2019). Both documents have methods for measuring the performance of lifeline utilities in an emergency event. While these documents do provide frameworks for measurement and analysis, they do not provide guidance on required levels of service following a disaster event. Further, the means of measurement put forward in both documents tend to concentrate on network performance issues rather than on the outcomes of service provision that are most relevant to individuals and communities. For example, ISO37123 has as one measurement “percentage of critical facilities served by off-grid energy services” (International Organization for Standardization, 2019) and NIST has a measurement of percentage function restored of power (electricity) to “hospitals, police and fire stations/emergency operations centres” (National Institute of Standards and Technology, 2016). While both sets of measurements provide data at the city-level as a pre-disaster assessment for benchmarking against other locations, or as a measure for the emergency services or emergency management organisations to benchmark their anticipated performance levels against, these measures may appear less relevant to individuals in the community either pre- or post-disaster event. Further, only the NIST framework provides a form of measurement through time, covering the response and recovery phases following a disaster (through the days, weeks and months following an event). An early form of the NIST framework has been used by two US States to define their required and current levels of resilience (Oregon Seismic Safety Policy Advisory Commission, 2013; Washington State Seismic Safety Committee Emergency Management Council, 2012). While

these provide an example of defining required emergency levels of service and present modelled estimates of infrastructure outages, they are still in a framework that may not appear relevant to individuals in the community due to their high-level measures on issues that may not appear relevant to post-disaster delivery of services.

More detailed emergency levels of service exist for some utility sectors. For example, the Sphere Handbook provides an excellent and well-researched set of ‘standards’ (or levels of service), and guidance, for potable water, sanitation, shelter and food provision, amongst others (Sphere Association, 2018). These standards help both the providers of the service (whether governmental or non-governmental) know the minimum level of service that should be delivered to individuals and communities, and lets the individuals and communities impacted know what level of service they could expect to receive.

The availabilities of water, food and shelter, as covered by the Sphere Handbook are based on human rights concepts (Sphere Association, 2018; United Nations Economic and Social Council, 1999; United Nations General Assembly, 2010). These levels of service are good starting-points for the consideration of emergency levels of service for the Wellington region, New Zealand. However, recommended levels of service for other utilities such as power supply, road access or telecommunications availability are less readily identified and there is a lack of recommendations or guidance for those sectors in either academic or other literature. For those sectors, the academic literature available is strong on aspects of mathematical analysis and modelling of outages, which allows utility owners to understand the mechanics of the management of their networks, however, it does not help the end-user understand the potential level of service that may be available in their context or help identify a proposed level of service for planning purposes. Similarly, other literature (mainly in the governmental and utilities sectors) is light on the identification of emergency levels of service, except for measures of ‘network performance’, for example as used by Wellington Electricity which has “a measure of the total time, in minutes, electricity supply is not available to the average consumer connected to the network in the measurement period” (Wellington Electricity, 2015, p. 22). Finally, documents such as the Sphere Handbook are aimed generally at low-income and potentially distressed environments such as rural African contexts or refugee camps. An understanding of levels of service to be delivered in an emergency in a high-income context such as the Wellington region in Aotearoa New Zealand is not well covered by such documents.

### 1.3.2 Gaps in the existing research

In most cases, the literature is not strong on identifying base-level or starting-point recommended emergency levels of service for most lifeline utilities. Few frameworks exist for recommendations on levels of service during or following disasters in high-income countries. The frameworks that exist either have no levels of service inserted (NIST) (National Institute of Standards and Technology, 2016) or, as in ISO37123 focus on utility network inputs rather than outcomes (International Organization for Standardization, 2019). Additionally, there is limited literature on most aspects of individual or household needs in an emergency, which would be required to populate a framework with.

Other literature does note that there is a need for the identification of emergency levels of service (Chamlee-Wright & Storr, 2010; Federal Emergency Management Agency, 2016). The absence of identified emergency levels of service for lifeline utilities in a high-income but disaster-vulnerable context is a research gap that this study aims to partially address.

## 1.4 Research questions

The research problem highlights that there are two research gaps. Firstly, the lack of any framework for PELOS and secondly the lack of evidence-based levels of service relevant to households.

The primary purpose of this research is to undertake research to create an evidence-informed framework for the identification of emergency response and recovery levels of service which could be applied across multiple situations/locations. A secondary purpose is to apply the framework and identify, where possible, 'planning emergency levels of service' (PELOS) that can be adopted for the Wellington region, Aotearoa New Zealand.

The aim, and heart, of the research is to address the following questions:

- Can a framework for, and including, emergency levels of service be created that aligns with international literature and best-practice in the relevant sectors?
- What is needed to develop a framework relevant to the Wellington region, to define and order planning emergency levels of service, that would allow interpretation by key stakeholders?

- What ‘planning emergency levels of service’ for each infrastructure sector could be defined, relevant to the Wellington region?

This thesis has been carried out as a ‘thesis by publication’. This means that some sections of this thesis have been submitted to, and published in, peer-reviewed journals. These sections are highlighted at the start, showing where the relevant section has been published. The initial and later sections of this thesis provide the overarching context, methodology and discussion for the thesis.

Regarding the structure of this thesis, the next section (Section 2) outlines the research position for this thesis. Section 3 details the methodology and research methods that were used to explore the research questions. Section 4 (paper 1) presents the literature review and preliminary framework. Section 5 (paper 2) presents the full ‘operationalised framework. Section 6 (paper 3) explains the full process for creating the framework. Section 7 details how the mapping tool, which provides a visualisation of where PELOS can, and can’t be achieved, was produced. Section 8 includes the thesis discussion with the Conclusion provided in Section 9.

## **2 Research position, methodology, and positionality**

Prior to undertaking research, it is essential to consider the research position and methodology that might best apply to a topic area, and the questions that are to be explored. After an explanation on the researcher's working roles (which are significant as they provide the context for why research strategies were chosen for this thesis), this section focuses on how this research fits within wider research and learning methods. It goes on to reflect on how the research methods chosen for this work fit with the author's own philosophies and thought processes.

### **2.1 Alignment between this research and the researcher's work with the lifeline utilities**

The author's work role with WREMO, the Council Controlled Organisation tasked by the regional and local councils of the Wellington region to carry out emergency management planning functions, is as the 'Project Manager of the Wellington Lifelines Group' (WeLG) and as the Wellington region 'Lifeline Utilities Co-ordinator'. As the Project Manager of WeLG, he works with the lifeline utilities to facilitate work on risk reduction in the region, specifically related to resilient infrastructure analysis projects. The Wellington Lifelines Group has existed since 1991 and has run various projects with the lifeline utilities on understanding the risk to the region and the potential impacts of hazard events (Wellington Lifelines Group, n.d.). The Group includes most of the lifeline utilities working within the Wellington region.

The Wellington Region Civil Defence Emergency Management Group Plan 2019-2014 has the purpose of "... enable[ing] the effective and efficient management of significant hazards and risks for which a co-ordinated emergency management approach will be required" (Wellington Region Emergency Management Office, 2019, p. 10). In other words, this plan outlines how the region can plan for, and respond to, hazard events. The purpose of this plan is, amongst other objectives, to create a space where collaborative planning can be carried out between the key stakeholders in the region, including the councils, emergency services, central government, iwi, the lifeline utilities and the community. It is the author's role, as the current Lifeline Utilities Co-ordinator to work with the lifeline utilities on emergency management tasks, and the expectation is that the lifeline utilities participate in such planning (which in all

cases in the past few years, they have been). Meanwhile, it is the author's expectation that the critical infrastructure entities manage their own risk levels and provide/restore levels of service during an emergency. These roles have been held by the author from 2011 until the present (2023).

Given the situation of the researcher as the Project Manager of WELG and the Lifelines Coordinator within WREMO, with access to key stakeholders, and with an extensive background knowledge of the context of infrastructure in the Wellington Region, there was a unique opportunity for research to be conducted on emergency levels of service for lifeline utilities. The output from this research will be used by the key stakeholders, which is an important means of putting the research results into practice.

The above work has implications for the chosen methodology for this research, specifically the choice of methodology used for this research.

## 2.2 Ontological and epistemological positions

Section 1 outlined 'what' is to be researched in this thesis (the research problem and research questions). For considering 'what' is to be researched can be related to 'how' it is researched, Grix (modified from Hay, 2002) proposes the interrelationship between the building blocks of research, as shown in Figure 2:

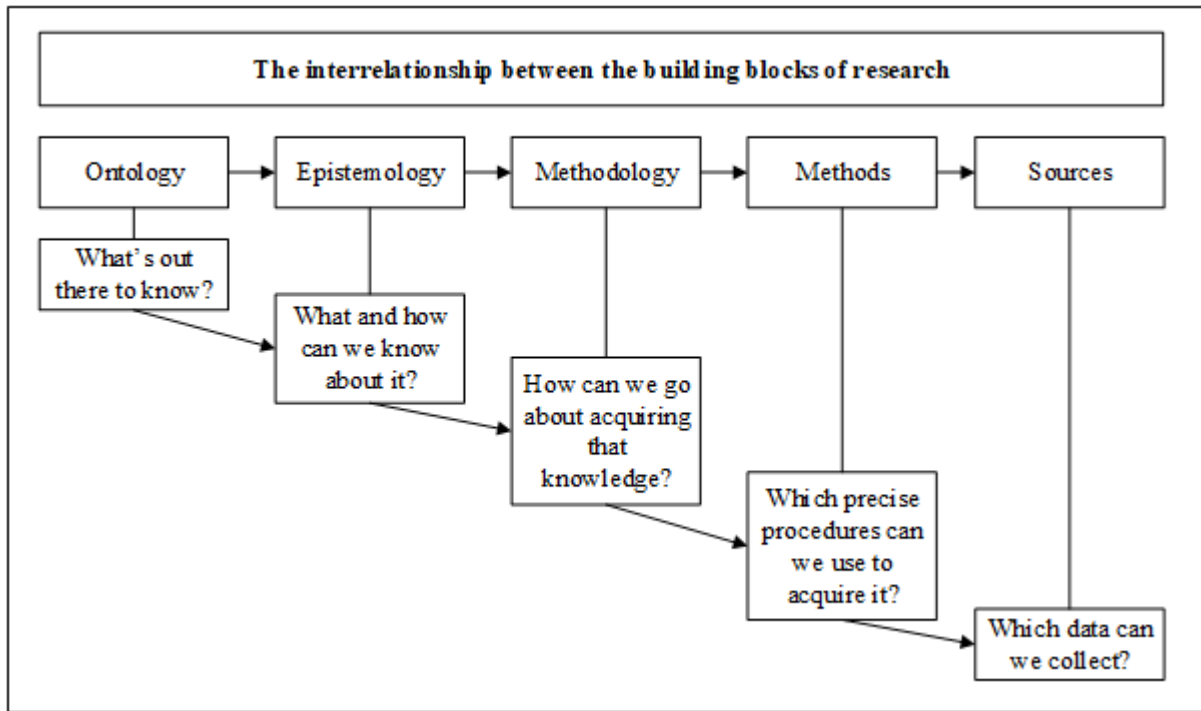


Figure 2: Grix's interrelationship between building blocks of research. Source Grix, 2002, modified from Hay (2002).

Figure 2 provides a process and understanding of how the building blocks of research design broadly flow. While it shows the building blocks of the research interrelationships in at a relatively high-level, it provides a step-by-step guide on how to build the stages of research, and the following sections of this report are ordered in the process proposed by Grix.

Grix (2002, p. 179) states that “by setting out clearly... what a researcher thinks can be researched (their ontological position) ... students can begin to comprehend the impacts one’s ontological position can have on what and how we decide to study.” The author’s values should therefore be explored to give a grounding for the ontology for this research. This has been carried out using the following method.

Using a tool created by Bristow and Saunders titled the Heightening your Awareness of your Research Philosophy (HARP) tool, (Saunders et al., 2016, pp. 153-156), the author answered a simple questionnaire based on the research ‘onion’. This gave the following scores on the alignment of his philosophy with different research philosophies (Table 1).

Table 1: The author's alignment with different research paradigms using the HARP tool

<b>Research philosophy</b>	<b>The researcher's HARP score</b>
Positivism	-4
Poststructuralism / Postmodernism	7
Critical Realism	5
Pragmatism	4
Interpretivism	7

The above demonstrates that the author's research philosophy aligns reasonably well with poststructuralism /postmodernism, critical realism, pragmatism and interpretivism. The positivist research philosophy is less well-aligned and is not considered further.

### 2.2.1 Ontology

Ontology is classification and explanation of entities. The research philosophies can be summarised as shown in Table 2:

Table 2: Research philosophies - overview (adapted from Saunders et al (2016, pp.136-137)

<b>Research philosophy</b>	<b>Selected epistemology, role of values and typical methods</b>
Positivism	Scientific method, observable and measurable facts. Researcher maintains objective stance. Typically quantitative, but a range of data can be analysed.
Poststructuralism / Postmodernism	Focus on absences, silences and oppressed/repressed meanings. Researcher and research embedded in power relations. In-depth investigations of anomalies, silences and absences.
Critical Realism	Knowledge historically situated and transient. Researcher acknowledges bias by world views, cultural experience and upbringing, but tries to minimise bias and errors. Range of methods and data types to fit subject matter.
Pragmatism	‘True’ theories and knowledge are those that enable successful action. Research initiated and sustained by researcher’s doubts and beliefs. Range of methods: mixed, multiple, qualitative, quantitative, action research.
Interpretivism	Focus on narratives, stories, perceptions and interpretations. Researchers are part of what is researched, subjective. Small samples, in-depth investigations, qualitative methods of analysis, but a range of data can be interpreted.

From the description of this research, as provided in Section 1.1, it is clear that this research does not align with a positivist approach, as this research is not based in measurable facts and will not require observations of social realities to produce law-like generalisations. That would be a ‘hard’ approach to a research issue that will require judgement and negotiation between competing viewpoints to create an emergency level of service framework. However, several philosophies do broadly align with this research (particularly critical realism and interpretivism). This suggests that there is little justification in taking a ‘short-cut’ in using the pragmatism approach, where ‘successful action’ is the key output, as there are sufficient approaches that allow for appropriate analysis of these research questions, and the pragmatism philosophy is therefore also discounted for this research. The post-modernism philosophy is less relevant to this research as that philosophy focusses on power relations that sustain

dominant realities, which is not the focus of this research. This research is therefore most likely to come under either the interpretivist or critical realism philosophies.

Scotland (2012, p. 13) describes the critical paradigm as follows:

“The ontological position of the critical paradigm is historical realism. Historical realism is the view that reality has been shaped by social, political, cultural, economic, ethnic, and gender values... Realities are socially constructed entities that are under constant internal influence.”

Also, Scotland (2012, p. 14) states that within this philosophy, “participants are involved in the research process, for example designing questions, collecting data, analysing information and benefiting from research (Creswell & Creswell, 2018, p. 9)... Critical methodologies include... action research (a cyclical process of investigation, action and evaluation which results in a change in practice)...”. Similarly, Patton (2015) sees the critical realism philosophy as critiquing an existing situation and using the findings to mobilise and inform change. This research aims to transform practice in the measurement of, and creation of goals for, emergency management in the Wellington region therefore is well-aligned with ‘critical realism’ philosophy.

Saunders et al. (2016) describe the interpretivist philosophy as creating new interpretations of social worlds and contexts. In this philosophy the interpretations of different individuals or groups should be understood and considered. Scotland (2012) outlines that the interpretive paradigm provides insights and understandings of behaviour in a context in which knowledge is constructed through interactions between people and the world around them. It may be used for research that involves open-ended interviews and focus groups and/or workshops. It therefore provides some alignment with this study. However, Saunders et al. (2016) propose that the interpretive paradigm brings into question the validity of knowledge as a foundational base due to the differing interpretations that individuals will have of their own view of situations and issues. This means that while this paradigm allows for open-ended questions and issues, generalisations useful for policymakers can be absent. In a way, this philosophy is about acknowledging that reality is subjective and differently constructed by individuals, whereas this work is more about building a shared understanding and agreed-upon approach. This proposed research therefore is not seen as coming under the interpretive philosophy.

While this research aligns mostly closely to the ‘critical realism’ philosophy, it should be acknowledged that (Scotland (2012, p. 14):

“Most of the leading authors in the critical paradigm have been male, prompting feminists to criticise the critical paradigm as excluding the voices and concerns of marginalised groups (Burbules et al., 1999). Ironically, the critical pedagogy can be accused of maintaining societal status quos.”

Therefore, the author must be aware of this aspect, particularly as the majority of those that are included in the data gathering process (the interviewees) are also predominately Pakeha (European), male, middle-aged, middle class New Zealanders. For this reason, the methodology must allow for the inclusion of other perspectives, including from the community. One way of overcoming this limitation is by the inclusion of other voices in focus group discussions. This is again in line with the critical realism philosophy, involving other voices within the research process.

Another aspect raised by Scotland (2012, p. 14) regarding the methodology used in the critical paradigm is that “if participants try to please the researcher, the data given may not be accurate and the research findings may not be credible. Consequently, issues of collaboration, consent, coerciveness, and autonomy must be considered.” For this reason, within the methodology, and specifically in the interview process, it must be clear that the ownership of the framework created must be common (i.e., owned by the Wellington Lifelines Group) rather than by the lead researcher. This will therefore assist the grounding of the collaborative and common output of the research. This is again in line with the aims and expectations of the use of the action research methodology.

As the critical realism paradigm has been established for this research, the research epistemology can now be considered.

### 2.2.2 Epistemology and research strategy

Action research is a typical methodology associated with the critical realism paradigm. McNiff (2013, p. 29) states that:

“Action researchers see knowledge as something they do, a living process. People generate their own knowledge from their experiences of living and learning. Knowledge is never static or complete; it is in a constant state of development as new

understandings emerge. This view of knowledge regards reality as a process of emergence, surprising and unpredictable....”

McNiff sees that action researcher/practitioners work in environments with other practitioners in which negotiation is required to progress, and where learning (for both researcher and practitioners) is therefore created. The General Teaching Council for Wales (2002, p. 15) sees action research similarly: “Action research is a term used to describe professionals studying their own practice in order to improve it”. Looking forward, action research is (McNiff, 2013, p. 23):

“... a name given to a particular way of looking at your practice to check whether it is as you feel it should be. You may be checking it as part of your critical reflection on your practice... Because action research is done by you, the practitioner, it is often referred to as practitioner research. Or practice-led research. It is a form of on-the-job research... It involves you thinking carefully about what you are doing, so it becomes critical self-reflective practice”.

The above steps demonstrate a notably clear alignment with this research on PELOS. It would appear therefore to be a straightforward step to adopt the action research methodology to this research, as opposed to a ‘standard’ methodology process such as outlined by authors such as Flick (Flick, 2015). There is however one aspect in which there is not clear alignment in that action research is normally used for continuous improvement. McNiff (2013, p. 57) and Cardno (2003) see action research as having loops of “plan, act, observe, reflect, plan...” Costello (2003, p. 7) sees it differently, noting that action research can involve a single cycle of “planning, acting, observing and reflecting”. This potential involvement of loops of research is an aspect that does not align perfectly with this proposed research, as this research will not allow for more than one loop of ‘plan, act, observe, reflect’, as the key stakeholders in this research (effectively the Wellington Lifelines Group) have limited capacity to support research, as they have other time pressures on their work. The implication for this research is therefore that while there is an excellent fit with the action research methodology, the lack of loops of learning mean that the fit is not perfect. Therefore, this research takes forward the main principles of action research, but not the repeated loops of continuous improvement (which aligns with Costello’s thoughts). The research does, however, reflect on what the next steps should be for any further or ongoing research. In this way it at least informs any continuous improvement for whichever researcher may take on any related research work.

This thesis therefore adopts the action research methodology within the critical realism paradigm for conducting this research.

### 2.2.3 Values and motives

McNiff (2013, p. 96) states that “doing action research means you consciously hope that something is going to change. You take action to try to let the change happen, and possibly to influence it. At this point, you need carefully to consider your motives in wishing to take action.”. For this, McNiff considers it essential to reflect on the values of the researcher, a step I also believe to be important, as it helps to define why I am doing this research, and why some of the (likely) themes of the research emerge. Reflecting therefore, my values and motives are as follows:-

**Equality and equity:** while total equality for all members of society on all matters is, effectively, an impossibility, I believe it is ultimately to the benefit of all members of society to have equal access to resources and opportunities.

**Respect for others’ perspectives and values:** I recognise that I am largely the product of ‘middle class England’. As a white middle-aged male who is a civil engineer, I have been moulded by the culture I grew up in. Clearly, I recognise that others have different values to me and different perspectives – something that has been obvious to me since an early age. Exposure to other cultures (I worked in Ethiopia, Singapore, and Uzbekistan for a total of eight years) mean that I have an appreciation that many people have quite different values and perspectives to mine. I have learnt to appreciate that other people’s values are shaped by their contexts, and that there are good reasons for them taking their perspectives and acting as they do – normally with approaches every bit as valid as my own approaches in my own context. In those other contexts, while sometimes I ended up asking “why do you do it this way”, I often come to realise that their ways of doing things were not only better for that context, sometimes they were better for any context. I therefore realise that through discussion I can learn how and why things are done differently in other contexts. While at a quite different scale, this is fundamental in my role in Aotearoa New Zealand in emergency management, where I interface with various organisations who carry out their own work in different ways.

**Self-interest:** this is probably not considered a ‘nice’ value by most people; however, I must recognise that while some of my actions are motivated by love or kindness (particularly to

those close to me), some of my actions are motivated by self-interest. This partially opposes the value of equality and has the outcome of pushing me to understand that my motivations for some actions, perhaps such as carrying out this research, are partly from a desire to improve my own situation.

**‘Do no harm’** (or even better, ‘do good’, or ‘work to improve’): this is a key value in some environmental and health and safety philosophies and resounds with my own values of doing no harm to those that are impacted by my actions, which includes minimising harm both directly (from my immediate actions) and indirectly, for example considering wider impacts such as carbon emissions.

**‘Learning improves’**: this PhD research is my fifth engagement with higher-level education (previous study includes a Bachelor’s degree in civil engineering and three Masters degrees). Not only do I enjoy such experiences (again – relating to my own self-interest), I always learn new systems, ways of thinking or approaches. Always this has widened my understanding of my surroundings. In addition to the learning in the formal classroom setting, I value learning in other forms too, for example work on construction sites (comprising around eight years of my engineering career) has helped me learn a great deal about how to work alongside others.

While reflecting, it should be acknowledged that I am a white, middle-aged European male who has benefitted from a stable family life and from a solid school education, without significant external disruption. I am therefore from a very privileged background. Progress has been relatively easily attainable for me. This affects my view of the world and my belief in the possibility for me to make changes to the systems and environments I interface with. It almost certainly also impacts the way that others view me and listen to the way in which I articulate arguments and suggest paths forward. This obvious privilege allows me benefits which reaffirm, to me, the value in working towards greater equality and protection for those who may be vulnerable to events such as hazard events. I know that I will not be good at some tasks such as social work, but I can work to influence other systems in the engineering and infrastructure sectors. This is where I have based my work, and where this research is based.

Having considered how this research fits within wider research and learning methods, how the research is structured, following the ‘action research’ approach, will be demonstrated. The methods that are used to collect and analyse data to develop the PELOS concept will now be presented.

### **3 Research methods**

As with the research position and methodology, it is important to consider which methods are most appropriate to use within the overall context, so that data is collected that best informs the research questions. On that note, this section begins by considering the overall research strategy as it relates to ‘action research’. This is followed by highlighting how, as part of the strategy, the research could be broken up into distinct steps that align with the action research approach. The methods that were used to research these steps are then discussed afterward. Due to this thesis being carried out as a ‘thesis by publication’, there is some repetition of the following section within the individual papers presented in the thesis. This section provides the overarching view of the research methods, with the sections in the individual papers being relevant, largely, to those sections alone.

#### **3.1 Research strategy**

This research was carried out on a ‘Thesis by Publications’ format because this format matches the steps to be taken in the research and allows papers to be published, and feedback received, to enhance the following steps in the research. Further, this format has allowed the researcher to check key steps of the research with the lifeline utilities themselves, allowing all stakeholders input to the key processes and outcomes of the published research, as it progressed.

As discussed in Section 2, the adoption of action research principles for this thesis was seen as applicable and appropriate to this methodology. Some modification of the practice and use of the principles, for use in this study, was necessary. McNiff (2013, p. 90) describes the basic action research process as shown in the first column of Table 3.

*Table 3: Overview of steps to be taken in this research, in alignment with action research philosophy*

<b>McNiff research process</b>	<b>Steps in this research</b>	<b>Proposed research paper</b>
“We review our current practice; identify an aspect we wish to investigate; ask focussed questions about how we can investigate it;	a) Background, context and literature review.	Paper 1: Infrastructure planning emergency levels of service for the Wellington region, Aotearoa New Zealand – a preliminary framework (See Section 4.)
imagine a way forwards; gathered from the literature review.	b) Create a theoretical framework from sources	
try it out, and take stock of what happens; modify our plan in light of what we have found, and continue with the action;	c) Test and update the above framework (‘operationalise’ it) through interviews with sector and industry experts, and a community group, and update as necessary.	Paper 2: Infrastructure planning emergency levels of service for the Wellington region, Aotearoa New Zealand – an operationalised framework (See Section 4.)
evaluate the modified action; and reconsider what we are doing in light of the evaluation. This can then lead to a new action-reflection cycle.”	d) Compare, as a case-study, the operationalised framework against infrastructure outages modelled for the Wellington region and look towards potential further work, beyond this research.	
		Paper 3: ‘Creating a ‘Planning Emergency Levels of Service’ framework – a silver bullet or something useful for target practice?’ (Section 6) and Paper 4: ‘A new mapping tool to visualise critical infrastructure levels of service following a major earthquake’ (Section 7.)

## 3.2 Characteristics of qualitative research and why it is appropriate here

Flick (2015, p. 5) defines (qualitative) social research as "... the systematic analysis of research questions by using empirical methods (e.g., of asking, observing, analysing data)". By Flick's description, this thesis could therefore be seen to be 'social research'. This research is intended to create a 'comprehensive picture' of the case under study, namely the potential creation of PELOS for the Wellington region. This thesis is not about the measurement of quantitative dimensions of an existing, or future, concept, it is about creating a framework based on available information and opinions.

The creation of a high-level framework, and the creation of post-event levels of service based on literature and from practitioners' knowledge using a small number of participants (as to be demonstrated later, around 30 participants, plus one focus group and two workshops) required collecting the opinions of the interviewees. It was considered that the best way to do this was by a series of interviews in which the context of the PELOS was discussed before discussing features of the PELOS literature, the preliminary and operationalised frameworks (outlined below). With a relatively small set of interviewees, and the opinion-based nature of the information to be gathered, it was seen that this information gathering was not a data-driven (i.e. quantitative) but a knowledge-driven exercise. Qualitative methods therefore were most relevant to this research.

## 3.3 Data collection

This section will explain the research methods taken in the research. The following sections then describe in more detail how each of these methods fed into the different research steps.

### 3.3.1 Ethics approval

Ethical approval was required for this work. Due to the potential for conflicts of interest for myself as lead researcher utilising action research, a full high-risk application (see Appendix 2) was submitted to the Massey University Human Ethics Committee. No meeting with the Ethics Committee was required, however a single round of revisions was required to clarify

some issues and strengthen the information given to interview participants relevant to the ‘action research’ methodology. Specifically, the approval usefully highlighted how the separation of roles of the lead author, as researcher, and as Project Manager of the Wellington Lifelines Group, could best be managed. This led to the interviews being carried out in two parts – firstly from the role of Richard Mowll, researcher, followed by questions posed by Richard Mowll, the Project Manager of the Wellington Lifelines Group. The Ethics Committee were satisfied that interviews were separated out in such a way to manage the potential conflict of interest.

### 3.3.2 Interviews and workshops

For the interviews, 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. Twenty-nine semi-structured interviews were carried out with both representatives of their respective organisations and, in a few instances of informed individuals, of an hour’s duration or less. These interviews were conducted between September and December 2021, most of them online (Zoom), but two were in-person. 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 convened 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 future work on emergency management in the region.

The questions posed in the semi-structured interviews and at the group workshop are included in Appendix 5. From the interviews, a long list of suggestions as to how to improve the PELOS framework was created.

An 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 (three emergency management professionals (of which one was a community development person) and two consultants, one focussed on infrastructure emergency management issues and the other on urban planning and social outcome issues). 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.

Each of the above interviews and focus groups/workshops required for the above research were recorded, and transcriptions taken of those interviews. The transcripts were then used to analyse the responses received against the following categories:

- The structured interview questions (which related to the research questions).
- Comments on the PELOS in the framework, as developed up to that point.
- Impacts on any other aspects of the framework (other than the section under discussion in the framework).
- Any other intelligence or information of relevance to this research.
- Although not the primary focus, for completeness's sake, notes could were taken, where relevant, on methodological aspects, as follows:
  - Process notes (any methodological challenges or alterations suggested on the running of this research, either to improve this research, or to improve any following research to be conducted in this field).
  - Any other intelligence or information that may aid any follow-on studies or work following this research, including any personal notes.

The NVIVO software was used for transcription and coding of the interviews. Axial coding aligning with the research questions and the cells of the theoretical framework allowed quick comparison and aligning of interview responses with specific cells of the framework, as included in Section 6, Paper 3.

The information gathered through the interviews and workshops provided the basis for developing key themes on PELOS and provided information on creating an operationalised framework of PELOS. The operationalised framework process and outputs are included in Section 5, Paper 2, and the key themes and theoretical basis is included in Section 6, Paper 3.

The research methods were the same for the creation of the mapping tool (see Section 7, Paper 4). Detail of this process is given in 3.4.5 however once a mock-up of the mapping tool was created, it was tested in a workshop with participants sourced by WREMO from local community groups. This session was not recorded; however, notes were taken at the session which were used to find out whether the mapping tool was of value, and to update features of the tool to make it more intuitive to use.

### 3.4 Research process in detail

Now the methods to be used in the research have been described, and it is clear that this thesis will be carried out by publication, how these methods were applied at each stage of the research process will be outlined. This section is organised in terms of the papers produced.

#### 3.4.1 Paper 1: Literature review and creation of a preliminary framework

To meet the objectives for steps a and b (Table 3), a literature review as described above was carried out to establish the existence of any frameworks for post-disaster utilities functionality, or that cover the benchmarking or measurement of ‘resilience’ (as such frameworks may provide guidance on how new frameworks can be created). The review aimed to identify any individual levels of service (i.e., for the energy, water, transport and telecommunications sectors) that exist. This informed what existing standards could have been adopted, or adapted, for use in the context of a Wellington Region framework. The review addressed the following questions (adapted from Flick (2015, p. 63):

- What theories/frameworks are used and discussed for emergency levels of service either at regional/city level or for individual lifeline utilities? (Initially the Sphere Handbook, Washington State and Oregon State frameworks were known. Were there others?)
- What is already known about emergency levels of service for individual lifeline utilities (i.e., what stated emergency levels of service currently exist)?
- What are the theoretical debates or controversies regarding the creation of emergency levels of service?
- What has not yet been studied?

In some sectors the literature review identified multiple suggestions or aspects of emergency levels of service used in other contexts or sectors. In other sectors there was limited literature available. In either case, the practitioners at WREMO (as part of the action research methodology) met to discuss the alternatives and proposed levels of service for the preliminary framework. These approximately five meetings involved only three practitioners, in which the available literature was discussed, and preliminary levels of service discussed. As more literature was found, subsequent meetings provided updates to the preliminary levels of service. This aspect is further discussed in Paper 1, Section 4.

### 3.4.2 Paper 2: based on research, present an operationalised (updated) framework (qualitative research)

#### 3.4.2.1 *Context for the data gathering*

This part of the research is aligned with step c (Table 3) and was the fundamental new research carried out in this thesis that tested and updated the preliminary framework developed in steps a and b. For data gathering, as already discussed, this research focussed predominantly on structured interviews with sector and industry experts. This process had to be a collaborative process for two key reasons. Firstly, for the lead author's work with the Wellington Lifelines Group (WeLG) any framework produced had to reflect the needs and opinions of the lifeline utilities of the region (but equally could not be a simple repetition of, for example, low or easily achieved emergency levels of service). Secondly, because the action research principles define that such a process should be mutually reciprocal, allowing both lead researcher and interviewees/participants to “participate in a process that allows critical thinking and practice in the wider world” (McNiff, 2013, p. 105). The context given at the start of each interview

reflected this exchange of information and opinions, and the structured interview questions reflected this collaborative approach.

Following on from the above, during the structured interviews, in addition to the requirements of the ethics approvals, interviewees/participants were asked to state whether their preference was to publicly release the finalised framework, or some other form of finalisation of the framework. (The process for this is covered in Paper 3 (Section 6)). This reinforced the approach of producing something collaboratively between the researcher in his role as Project Manager of WeLG and the various key WeLG members and stakeholders, as identified below.

#### *3.4.2.2 Research design: sampling, comparison, expected numbers of participants*

Finding subject matter experts for this research was a relatively simple task. Key stakeholders (i.e. staff working at the lifeline utilities in the Wellington region) bring specific insights due to their roles in working with lifeline utilities, and through their roles in key stakeholder organisations that have influence over the emergency management process in the Wellington region, or who have knowledge that could enhance any framework produced. This research therefore used ‘purposive sampling’ as the above stakeholders were “very relevant for the functioning of a programme under study” (Flick, 2015, p. 105), and were relevant for the action research methodology. The numbers of such stakeholders were relatively low, with each lifeline utility generally having one or two people having good knowledge of both their managed utility networks and knowledge of emergency management through their engagement as members of the Wellington Lifelines Group work. This meant that the potential interviewees for each lifeline utility were relatively easily identified.

Based on the creation of the preliminary framework and having established the stakeholders to be interviewed for this research, the field research then commenced. This involved two strands of research interviews:

Firstly, emergency management practitioners and managers in fields related to policy formulation affecting infrastructure, within the Aotearoa New Zealand setting were interviewed through semi-structured interviews to test the theoretical framework. The reasons that the semi-structured interview format was chosen were that: due to the range of sectors (infrastructure sectors and emergency management) a broader, more open set of questions allowed for responses to be gathered on the key points; and that a structured set of questions would not

have led to the interviewees being able to provide contextual information or other related/relevant thoughts. These interviews gathered information that gained insights into the practicability of the theoretical framework and provided information on how aspects of the framework could be improved. Further semi-structured interviews were then conducted with industry / sector experts for individual sectors, for example within the energy, telecommunications, transport, and water sectors. In all, twenty-nine semi-structured interviews were carried out, with one hour being booked for the meetings (average duration of interview was 37 minutes, the shortest being 19 minutes, and the longest 62 minutes). This industry research informed the individual sector-specific elements of the framework, ensuring that they were relevant to the sector concerned and relevant to how any measure could be measured and implemented. Where more than one person in a specific organisation was to be interviewed (e.g., at some lifeline utilities, both the Asset Managers and the Operations Managers had relevant opinions on this subject), so both were interviewed together.

The sequence of interviews was:

- Interview national, regional, and local Civil Defence and Emergency Management (CDEM) managers and Civil Defence Emergency Management Controllers to gain an overview of emergency management.
- Interview lifeline utilities staff, for insights (technical and strategic) on individual cells within the framework.
- Interview remaining stakeholders and sector experts (national and local).

The above sequence of interviews allowed for overarching issues to be identified (strategically) regarding a framework and technical aspects of any proposed PELOS to be explored and any issues identified. Once overarching issues had been identified, the technical input from the lifeline utilities then allowed for individual issues within the framework to be adjusted, where necessary. Updates suggested to the framework were carried out after each interview, meaning that the framework was in a constant state of improvement and adjustment as interviews proceed. Because of this, a final workshop was held which helped those interviewed at the start of the interview process to see the updates and provide any final guidance / input to the updated version. For the interviews,

Table 4 shows the demographics of those interviewed.

*Table 4: Demographics of interviewees (Total participants = 30)*

Male	29
Female	1
Aged 18-24	0
Aged 25-34	0
Aged 35-44	0
Aged 45-54	8
Aged 55-64	19
Aged 65+	3
Identifies as Māori	2

The advantage of carrying out the above process as a series of individual interviews rather than as a single large workshop was that each interviewee could provide their inputs in a focussed manner, and their insights used to maximum advantage in the research. A final workshop was held (duration 126 minutes), following the interviews, which allowed for all insights to be given by the key stakeholders (which included the members of the Wellington Lifelines Group and other key people, such as staff at the National Emergency Management Agency) as a group, which was found to be sufficient to round-out the information gathering in this research.

Secondly, the framework was tested against a focus group of residents from the Wellington region (duration approximately 40 minutes). This aspect of the research identified whether the preliminary theoretical framework was understandable by lay people, and whether individual elements of it were relevant and informative for emergency planning purposes. This allowed for local / community views to be considered. While the focus group could have led, to an extent, to ‘group think’ (i.e. participants in the session could adjust their thoughts based on the evolving conversation) (MacDougall & Baum, 1997), the workshop process allowed for ideas to be ‘bounced around’ on the framework. The participants in the workshop were taken from the Wellington Water community engagement group, which is a small group of Wellington region residents, created through the help of Colmar Brunton (a New Zealand research company) who were happy to be engaged on water delivery and emergency management issues. The researcher’s contract work with Wellington Water enabled such a process.

It can be seen in

Table 4 that there were limited numbers of Māori interviewees. This is due to the demographics of the key staff at the critical infrastructure entities and in emergency management at the time the interviews were conducted. Despite this, at the same time that the interviews were being conducted, the National Emergency Management Agency was conducting consultation on a replacement to the Civil Defence Emergency Management Act (Civil Defence Emergency Management Act No 33, 2002) in which there was to be greater Māori involvement in emergency management. The subsequent Bill (Emergency Management Bill, 2023) does include greater Māori representation in emergency management, and it was within this context that this research was being conducted.

The demographics of the focus group were as shown in Table 5.

*Table 5: Demographics of focus group (Total participants = 7)*

Male	5
Female	2
Age ranges	Data not collected
Identifies as Māori	Data not collected

In this way, the process of conducting the interviews took the stages outlined in Table 6.

Table 6: Stages to update the preliminary framework to the operationalised framework

Stage	Action	Comments
1	Interviews of emergency managers	
2	Iteratively update preliminary framework, based on above interviews	
3	Interview lifeline utilities managers	
4	Iteratively update framework, based on above interviews	
5	Interview sector stakeholders	
6	Iteratively update framework, based on above interviews	
7	Carry out focus group discussion using the WREMO community group (noted above)	
8	Update framework, based on above focus group	
9	Workshop updated framework with emergency management and lifeline utilities key staff	
10	Final update of framework based on workshop	
11	Write up findings	See below. Forms ‘papers 2 and 3’ of this research

The above research was used to update the preliminary framework, into what will be termed the ‘operationalised framework’.

### 3.4.3 Paper 3: ‘How to’ create a PELOS framework

The fourth paper, comprised step d (see Table 3), and addressed the following aspects of the research:

- Can this framework be used in other contexts (in other parts of NZ or internationally)?
- How would anyone in another context follow the process to achieve the same result?

Paper 3 was written to address the above questions, and to delve deeper into concepts such as interdependencies, 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. As the interviews for the operationalised framework progressed, and from discussions with wider stakeholders (not part of the formal research process presented in this thesis) it became apparent to the author that there were some key themes that were raised in discussions regarding the concept of PELOS. On investigation of the literature, it was found that previous studies either confirmed or questioned the nature of the themes. This paper explored those themes, as they were beyond merely identifying emergency levels of service in a descriptive sense. These themes are fundamental aspects that are important to the processes of successfully creating a PELOS.

It was found, during conversations with wider stakeholders, during the time that the research was conducted, that the above five themes were often raised. This paper therefore outlined how the themes could be considered in the creation of successful PELOS.

#### 3.4.4 Paper 4: A new mapping tool to visualise critical infrastructure levels of service following a major earthquake

The final aspect of the research (step d in Table 3) was to test the resulting PELOS against infrastructure outage modelling carried out for the Wellington region. It was originally intended that this would be carried out through the presentation of a table, or similar, broken down into suburb-level analysis of where levels of service could, and could not be achieved. However, as the research for this thesis progressed, it was found that a mapping-based presentation (mapping tool) would produce significantly better results. This modelling was carried out in a collaboration with researchers at the University of Canterbury (New Zealand). The information used in the modelling (for the gap analysis) was produced for a Wellington Lifelines report (Wellington Lifelines Group, 2019), which presented modelled infrastructure outages following a rupture of the Wellington fault. Using GIS-based computer modelling, aspects such as walking distances for each dwelling in the Wellington region to emergency supplies (such as water and food) were presented. A workshop was undertaken with a further community group, to ensure that the resulting web-based tool was understandable by members of the public. The demographics of the workshop participants are shown in Table 7.

*Table 7: Demographics of mapping tool workshop (total participants = 8)*

Male	2
Female	6
Aged 18-24	0
Aged 25-34	0
Aged 35-44	4
Aged 45-54	0
Aged 55-64	1
Aged 65+	3
Identifies as Māori	Data not collected

The details of how this additional workshop was structured, and the results from it, are in Section 7, Paper 4. Although an add-on to what was originally intended as part of this research, it was covered under the existing ethics approval for the research, and allowed for a visual representation of the achievabilities of the PELOS. This type of information could provide the community an understanding of the impact on them over the weeks and months following a rupture of the fault, and used to help them with planning for their own responses to an earthquake and also can be used by emergency management professionals to plan for such an event, with better knowledge of the numbers of people that are likely to be impacted, and to what degree.

The mapping tool is being continually developed and as such is an evolving tool.

The papers in this thesis follow – Paper 1 (preliminary framework) [Section 4], Paper 2 (operationalised framework) [Section 5], Paper 3 (‘how to’ create a PELOS framework) [Section 6] and Paper 4 (mapping tool) [Section 7]. These papers include their own methodology descriptions, along with the methods, data, analysis, results, and conclusions. Due to this, there is some natural repetition of content, for example, on methodology. The paper that documents the development of the preliminary framework follows here.

## **4 Paper 1: Infrastructure planning emergency levels of service for the Wellington region, Aotearoa New Zealand – a preliminary framework**

This section contains a literature review of texts that are relevant to the concept of ‘planning emergency levels of service’ (PELOS). These texts cover the context of setting PELOS and infrastructure-specific texts. For example, where there are texts relevant to the water sector, these are described. It then proposes a preliminary framework of PELOS, based on the literature review combined with perspectives of experts in the Wellington Region Emergency Management Office.

The statement of contribution sheet for this paper is in Appendix 1 of this thesis.

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## 4.2 Abstract

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

## 4.3 Introduction

Natural hazards have the potential to cause humanitarian impacts. In the past, earthquakes, tsunami, hurricanes and droughts have had devastating effects on communities. Although very different in nature, the outcomes of those hazard events on communities may have similar characteristics, such as loss of access to food supplies, loss of water supply and loss of power supply (Strömberg, 2007). Whether in a low- or high-income context, and whatever the cause of the infrastructure outage, people immediately affected by a major hazard event have needs, both in the short-term response and over the following months during their pathway towards longer-term recovery (Sphere Association, 2018). While such events may happen in any part of the world, some locations are known to be vulnerable to specific hazards, such as hurricane-prone regions, or seismically active areas (Behlert et al., 2020; D’Amico, 2016) such as Wellington, the capital of New Zealand.

There are known vulnerabilities in the various critical infrastructure networks in the Wellington Region, which make them prone to damage and disruption following hazard events. These are across the energy, telecommunications, transport (and consequently food delivery) and water

sectors. For example, following a rupture of the Wellington fault, reticulated water outages are anticipated to be between one and twelve months, and power outages between one week and six months (Wellington Lifelines Group, 2012, 2019; Wellington Region Emergency Management Office, 2019) (WeLG, WREMO).

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

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

The term 'level of service' (LoS) is used in this paper because it is a commonly used term in infrastructure asset management practices, where 'infrastructure is described by asset condition, performance and other relevant outputs' (Edwards, 2010). For example, it may refer to the quality or reliability of power supplies, quantities, and quality of water to be provided to end-users or surface condition on roads. If described well, such descriptions should also be able to be understood by laypersons. Adding the words 'planning emergency' shows that this measure is specific to the LoS planned to be delivered during or after an emergency or major event.

#### 4.4 Wellington region context

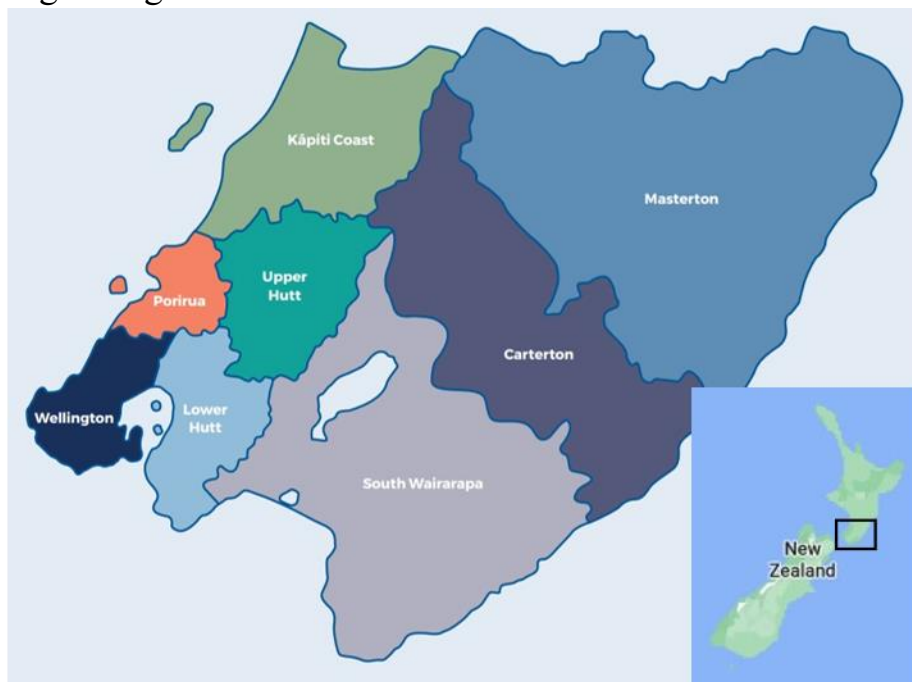


Figure 3: Local councils comprising the Greater Wellington region, New Zealand

Wellington City is the capital of New Zealand. The greater Wellington region is made up of eight local council areas (Figure 3). The hilly topography, the presence of active faults, liquefaction-potential soils and strong winds mean that the region is vulnerable to a range of hazards, including earthquake, tsunami and storm events (Wellington Region Emergency Management Office, 2019) all of which can lead to potential infrastructure outages. Further, due to its topography there are limited transport routes into and out of the region, which leaves the region particularly vulnerable to the consequences of earthquakes. The population density is highest in the Porirua, Upper Hutt, Hutt City (Lower Hutt) and Wellington City areas, leading to those locations sometimes being referred to collectively as the ‘Wellington metropolitan area’. While the Kapiti Coast also contains larger towns, parts of it, and the majority of the Wairarapa (covering Masterton, Carterton and South Wairarapa) are considered rural areas. This means that in the region, the densest infrastructure networks are in the metropolitan area, with either less dense networks, or private supply (i.e. for water) in the rural areas. This factor impacts the organisational make-up of the utility providers, for example Wellington Water serves the metropolitan area (and since 2021 the South Wairarapa). There are reticulated gas networks for the Kapiti Coast and Wellington metropolitan areas, but not in the Wairarapa. The main focus of this paper is on ‘urban areas’, and therefore is most focussed on the Kapiti Coast and metropolitan area issues, although it is likely that some of the concepts outlined in this

paper could be translated to the Wairarapa (rural areas), which will be the subject of future work.

The climate in the region is temperate, however occasional high windspeeds through the Cook Strait (between the North and South Islands of New Zealand, which is located in the ‘roaring forties’), leads to the nickname of Wellington as the ‘windy city’ (Deguara, 2021, June 22). This wind has impacted the design of the power supply network, which is relatively robust against high, but not extreme, winds, and has impacted the design of houses, buildings, and structures. Temperatures rarely drop below freezing, however the heating of dwellings is still needed, most normally carried out by electricity or gas-powered heating.

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

## 4.5 Methodology

### 4.5.1 Literature review methodology

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

- Post-disaster goals, performance levels, availabilities
- Disaster standards

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

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

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

As an addition to the above searches, the references and ‘further reading’ lists at the ends of chapters in the Sphere Handbook (Sphere Association, 2018) brought forward a rich set of references that were relevant to this literature review. All references were captured and organised using EndNote.

#### 4.5.2 Framework creation methodology

Regoniel (2015) describes the four steps of how to create a conceptual framework as: choose [the] topic, do a literature review, isolate the important variables, and generate the conceptual framework. Here, guided by the results of the literature review, and using the action research methodology (McNiff, 2013), the authors created the preliminary framework through a series of practitioner discussions in which the key variables (infrastructure sectors) were discussed individually. The framework (in Table 10) was built up through these discussions. These discussions were held between the Community Resilience and Recovery & Group Recovery Manager (WREMO), the Lifeline Utilities Co-ordinator (the lead author of this paper) and a WREMO Emergency Management Advisor. Between them, these people had a total of over 25 years of experience of working in emergency management in the Wellington region, covering community engagement, emergency planning, engagement with the lifeline utilities (critical infrastructure providers) and recovery planning. Two of the people had worked in developing country contexts, giving them an understanding of emergency or low-cost delivery, as relevant to the Sphere Handbook (Sphere Association, 2018). Discussions centred initially on the need for, and broad structure of, the framework, which led to the table format of the framework. As the literature review progressed, meetings then centred on individual cells of the framework.

Where no obvious or available LoS were found in the literature, for example for power supply, the authors proposed new LoS. In most cases, the LoS presented in the preliminary framework have not been the subject of detailed research or deep investigation and are based on the opinions stated at the meetings, and consequently require further research. Generally, as will be seen in Section 4.7, the discussions balanced the ‘ideal’ (i.e. full delivery of services without disruption, or alternatively LoS identified in literature) against the modelled outages given in the WeLG Programme Business Case (Wellington Lifelines Group, 2019), which were considered a ‘worst case’ set of infrastructure outages that could impact the region. The aim of the discussions was to identify what the needs of individuals are, for a basic service, and use that as a goal (or, in this case, LoS) for delivery. There were no fixed questions or agendas, or formal means of analysis for these meetings, instead using the issues raised through the literature review to prompt discussion. The above meetings and work were carried out under a low-risk ethics notification via Massey University, New Zealand.

## 4.6 Wider issues regarding the setting of ‘emergency LoS’

Section 4.6.1 of the results highlights initial context-setting information that was found in the literature review, and deemed to be important when developing LoS. These include wider issues, response versus recovery timeframes, the need for LoS and other existing frameworks. The next section 4.7 outlines how the preliminary framework and LoS were derived using a combination of the literature review and group discussions. Section 4.8 presents the overall framework in tabular format.

### 4.6.1 Wider issues regarding the setting of ‘emergency LoS’

#### *4.6.1.1 Human rights and response goals*

Some aspects of emergency provision can be linked back to human rights: the United Nations Economic and Social Council (1999) declared access to adequate food as a human right, and the UN General Assembly declared clean drinking water and sanitation a human right (United Nations General Assembly, 2010). The Sphere Handbook (Sphere Association, 2018, p. 8), which is largely focussed on low cost and humanitarian relief situations, explores this aspect,

and uses those human rights to help define standards for service provision. However, not all infrastructure services are identified as being related to human rights including, for example, the provision of a power supply (although power is required at an operational hospital, and healthcare is a human right), an issue which is explored further in the discussion section of this paper.

#### *4.6.1.2 Moving from response to recovery*

As Johnson and Olshansky (2017) explain, while the first-flush of response to an event may take weeks to months, “physical recovery from disasters takes many years...”. Haas et al. (1977) (cited in Johnson and Olshansky (2017)) provide a model that gives phases of recovery as ‘emergency’ (over the days following an event), ‘restoration’ (starting days after an event, and lasting up to 4 months), and ‘reconstruction I and II’ (lasting months to years). Using this scheme, the span of this paper predominantly covers Haas et al.’s emergency and restoration phases.

#### *4.6.1.3 The need to set LoS and setting them*

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

“Conforming to the Sphere standards does not mean implementing all key actions or meeting all key indicators of all standards. The degree to which an organisation can meet the standards will depend on a range of factors, some of which are beyond their control. Access to the affected population, or political or economic insecurity, may make achieving the standards impossible in some contexts.” (Sphere Association, 2018, p. 8)

The above demonstrates why the Sphere Association considers that standards should be in place for a response, but also sets context for the delivery of services, acknowledging that the nature of a hazard event may make some services impossible to deliver. The Handbook also

indicates that equity of delivery is also a goal – the delivery of services may not be to the stated LoS in some locations, and no delivery may be achievable at all in some other locations.

Bross et al (2019) argue that apart from the Sphere Standards, very few other disaster-context water standards exist that could be used for high-income contexts, and what standards exist, tend to focus on the management of utilities and service activities rather than on the quantities or quality of the output. Their paper argues that without standards or goals, emergency planning frameworks cannot adequately define the outputs required. This argument could be widened to apply to other infrastructure sectors.

#### *4.6.1.4 Measuring emergency performance of infrastructure – other frameworks*

There are various frameworks for the assessment (or measurement) of resilience. Three of these are for measuring city-scale resilience using qualitative measures - the UNISDR (Disaster resilience scorecard for cities), Rockefeller Foundation (City Resilience Framework) and ISO37123. None of the above frameworks provide any scale or recommendation on what is, or is not, considered resilient, or any target level of provision of the measurements given in the frameworks. While the number calculated for each measure could be compared against other cities or regions, the question of ‘so what?’ is not addressed well. The National Institute of Standards and Technology (NIST) framework (and its predecessors for San Francisco, and the States of Oregon and Washington) for ‘Community Resilience Planning Guide for Buildings and Infrastructure Systems’ (for the USA) is a framework specifically designed to be used by communities to develop performance goals for post-event LoS (National Institute of Standards and Technology, 2016; Oregon Seismic Safety Policy Advisory Commission, 2013; Poland, 2008; Washington State Seismic Safety Committee Emergency Management Council, 2012). This group of frameworks concentrate on, for example, the specifics of the functioning of an infrastructure network, providing a measure of aspects such as the ‘design hazard performance’ of the transmission and distribution (including substations) of electricity to ‘Hospitals, Police and Fire Stations / Emergency Operations Centres’. Three frameworks (SPUR, Oregon State and Washington State) have stated emergency levels of service, with timeframes for the restoration of services, alongside estimates of when services will be restored with the infrastructure at the time of the writing of the respective reports. While these three documents all include stated goals for the restoration of services, these are generally infrastructure service

‘input’ goals such as “electricity: distribution: 60% restored” (Washington State Seismic Safety Committee Emergency Management Council, 2012, p. 19) or specific road-based, for example “Tier 1” State Highway bridges will be opened by ‘day x’ (Oregon Seismic Safety Policy Advisory Commission, 2013, p. 143). These documents are incredibly valuable in setting expectations for both the infrastructure providers and the relevant communities on outage goals and likely performance levels.

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

#### 4.7 Deriving preliminary framework and LoS

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

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

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

(National Institute of Standards and Technology, 2016; Oregon Seismic Safety Policy Advisory Commission, 2013; Poland, 2008; Washington State Seismic Safety Committee Emergency Management Council, 2012)). The simplified timeframe used here was considered by practitioners to be appropriate for the region, and allows for the difficulties in predicting ‘exact’ timeframes for service provision.

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

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

#### 4.7.1 Water

##### 4.7.1.1 *Literature – water*

There is a comparative wealth of information on the needs of humans for a water supply, typified by Howard and Bartram (2003). Aimed at low-income and emergency environments, the World Health Organisation (WHO) and the Water, Engineering and Development Centre (WEDC) (World Health Organization & Water Engineering and Development Centre, 2013) suggest different stages of water needs - 5 litres/person/day for 2 weeks to one month following the emergency intervention (response) with a maximum distance of 1 km between shelters and water points, increasing to 15+ litres/person/day by 3 to 6 months from the initial intervention. A key principle is to aim for incremental improvements over time. The WHO states that in relation to the distance between the water collection point and the shelter, at either a distance of 1,000 m or a collection time of 30 minutes, the quantity of water collected is often below 5

litres/person/day, however with ‘optimal access’ quantities of 100 litres/person/day can be collected (World Health Organization, 2003). Distances beyond this mean that people tend to collect less water, potentially less than minimum requirements.

The Sphere Handbook defines a standard for water supply being 15 litres/person/day, within 500 m of the dwelling. The Handbook includes standards for water quality, collection time and queuing time, provides references relating to the standards within each category, and additional suggested reading on the subjects, providing good evidence for why those particular standards were selected (Sphere Association, 2018).

For high-income regions exposed to hazards, available information on LoS for water is shown in Table 8:

Table 8: Summary of water emergency storage and restoration goals

Location/context	Water storage recommendations and post-event restoration goals and definitions
<b>International</b>	
WHO (World Health Organization, 2003)	‘Basic’: 20 litres per person per day within 1km of the dwelling
Sphere Handbook (Sphere Association, 2018)	15 litres per person per day within 500m of the dwelling
<b>USA</b>	
State of Washington, USA. (Washington Emergency Management Division, n.d.)	1 gallon [of water] [approximately 3.8 litres] per person and pet per day for drinking, cooking and hygiene needs for ‘2 weeks’ should be stored as preparedness for an event
Oregon Office of Emergency Management (n.d.)	Emergency kits should contain ‘two weeks supply of food, water and other necessary supplies’
American Red Cross (n.d.)	Advise storing ‘one gallon per person per day’ for three days (for evacuation) and two weeks (for supply at home).
<b>New Zealand</b>	
New Zealand (Ministry Civil Defence & Emergency Management, n.d.)	3 litres per person per day for three days or more
Wellington Water (2018b, p. 33) (For further details, see below.)	A goal of delivering 20 litres of water, per person, per day, within 1 km of the dwelling, from ‘day 8’ after a major earthquake. ‘... provide 80% of our customers, within 30 days of a reasonable seismic event, with at least 80% of their water needs (80-30-80 Strategy).’
University of Canterbury Quake Centre et al. (n.d.)	‘may be microbiologically unsafe’ ‘tankers or standpipes available within 500-1000 m of home or minimum reticulated supply of 20 l/person/day’
For Auckland, Watercare (the Auckland, New Zealand, water supply utility), Buxton et al. (2015, June 25)	Definition of four ‘classes of water demand experience’: <ul style="list-style-type: none"> <li>• full water,</li> <li>• water restrictions are in place,</li> <li>• no reticulated water (or reduced pressure), and</li> <li>• water is available but not potable, i.e. requiring boiling or other treatment to make safe to drink.</li> </ul>
Proposed for Christchurch, post-earthquake of 2011 (Cubrinovski et al., 2011, p. 47)	Percentage of premises and critical facilities with water supply. For example: within 48 hours, 90% of domestic premises and 95% of critical facilities receive service. Within 1 month, 90% of city receives water confirming to NZ Drinking Water Standards.

Wellington Water additionally outlines that 3 litres water/person/day will cover drinking, cooking and hand-washing, while 20 litres/person/day will cover other activities including dish washing, cleaning wastewater buckets and other functions (Wellington Water, n.d.-b). Wellington Water (2018b, p. 33) has the goal of delivering 20 litres of water, per person, per day, within 1 km of the dwelling, from ‘day 8’ after a major earthquake, and for restoring services, aimed at resilience, ‘to provide 80% of our customers, within 30 days of a reasonable seismic event, with at least 80% of their water needs (80-30-80 Strategy).’ This strategy is based at the community-wide, or city-wide level, rather than at an individual or household level.

#### *4.7.1.2 Proposed LoS – water*

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

Wellington Water’s plan for water provision from ‘day 8’ following a major event is covered in their ‘Community Infrastructure Resilience’ project (Wellington Water, 2018a). An emergency water supply network intended to deliver 20 litres of water per person per day, within 1 km of the dwelling, has been developed, using emergency water sources such as bores and streams, and a supply network of transport and distribution bladders. This is also in line with the ‘basic standard’ detailed by the WHO (World Health Organization, 2003).

The practitioners decided that although the Wellington Water initiative only covers the Wellington metropolitan area, this level of service could also be appropriate for the greater Wellington region, including the Kapiti Coast and Wairarapa (all areas shown in Figure 3), so

is included in the framework (Table 10). This is the only sector in which the expert panel needed to apply only minimal judgement, or balance ‘ideal’ versus ‘likely’ delivery, due to the excellent information and LoS provided by the WHO and in the Sphere Handbook. The 80-30-80 strategy (Table 8) (Wellington Water, 2018b) is also adopted as the framework level of service for days 31 to day 90 following an event. The LoS taken for the water sector are therefore as shown in Table 10. Further work is required to understand the different characteristics of water supply in the urban vs rural areas. While the emergency plan outlined for the Wellington metropolitan area is a viable plan (where the LoS is for water to be available within 1km), distances for delivery will be greater in rural areas. It is also likely that a proportion of dwellings in rural areas may be on individual water supplies, in which case a LoS for centralised water supply will be less relevant. This is an area where further work is required to understand what LoS may be appropriate for water supply in rural areas.

#### 4.7.2 Road access

##### 4.7.2.1 Literature – road access

There is a wide range of literature on road access following an emergency, particularly on the analysis of road networks for their resilience or adaptability. Konstantinidou et al. (2014) reviewed a range of studies on pre- and post-disaster transport network availability. These were sorted into two categories – those that modelled post-disaster transport network performance and those that considered post-disaster decision-making for the network. One reviewed study included metrics for an “emergency facility-weighted” measure which uses formulae for calculating outages, but does not recommend actual outage timeframes or LoS (Zhang et al., 2018). The literature is heavily weighted towards modelling of the performance of road networks following disruption to the network to assist with decision-making. This is highly relevant to contexts where there are road networks that have multiple alternative routes, where traffic can be diverted, but less relevant to Wellington, where few viable alternative routes exist, and where single hazard events such as a large earthquake can impact many roads simultaneously.

The National Cooperative Highway Research Programme Transportation Research Board of the National Academies produced ‘A guide to regional transportation planning for disasters,

emergencies and significant events' (National Cooperative Highway Research Program Transportation Research Board, 2013). This document outlines 'how' to plan for transport outages, describing eight principles for emergency planning: a plan must be comprehensive, cooperative, information, coordinated, inclusive, exercised, flexible and continuous. This document provides a good basis for emergency planning but does not include goal setting.

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

For the performance of individual structures such as bridges, both the California Department of Transportation (2019) and Waka Kotahi NZTA state the return period design event that structures on 'important' or 'recovery' roads (Caltrans) or any State Highway (NZTA) should be designed for. While this provides guidance on the intended performance of structures to hazard events, these do not give network-level (i.e. road) performance levels.

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

Where road access is temporarily not available, many trips may be taken by individuals by active transport (walking and cycling), navigating around specific locations of road damage. There is a relative wealth of literature, particularly in urban planning and public health sectors, on feasible walking and cycling distances for individuals. A trip distance considered walkable or cyclable will differ between individuals (Ali et al., 2015; Langdon, 2017; Tao et al., 2020; Tsunoda et al., 2021). Further, there are differences in what will be acceptable to populations in different countries, for reasons that may include culture, availability of walking routes and cycling paths and proximity to facilities. A direct comparison of walking practices in the USA and Germany demonstrated differing active transport practices between people in those

countries, where there was a greater proportion of trips carried out by active transport in Germany compared to in the USA (Buehler et al., 2011). Despite such differences, understanding the public's walking habits and preferences can help understand the practicalities of active transport as an alternative to car travel (Table 9).

Table 9: Reasonable walking or cycling distances

Reference	Study context and location	Reasonable walking or cycling distances
Dora and Phillips (2000, p. 32) (WHO)	Transportation policy for European countries	The WHO advocates for policies that promote a shift to walking and cycling for “many trips shorter than 5 km”
Sphere Association (2018, p. 205)	Low cost and emergency response environments	‘... distance from dwellings to final distribution points or markets (in case of vouchers or cash): Target <5 kilometres’
Watson et al. (2015, p. S59)	Physical activity and health study, US adults.	‘47% [of adults] thought walking up to 1 mile was reasonable’ (p. S59) ‘45% of adults thought it would be reasonable to walk more than 1 mile [1.5 km].’
Badland et al. (2007)	Physical activity and health study, commuters in Auckland, New Zealand.	Over 60% of people considered it acceptable to commute between 2 and 4.9 km by transport-related physical activity (walking or cycling)
Yang and Diez-Roux (2012, p. 12)	Epidemiology (health), study in the USA.	‘The upper tail-ends of the distributions [of walking distances] can also provide a sense of the walking distance and duration that are actually achievable under certain circumstances.’

Reference	Study context and location	Reasonable walking or cycling distances
		Mean cumulative distance per day of those that walked was 2.3 km.
Larsen et al. (2010)	Urban planning, Montreal, Canada.	<p>The median distance for walking for shopping was 581 m and for cycling was 1,529 m.</p> <p>Around 1.7% of walking trips were of 2 km distance or more, and less than 1% of 3 km distance or more.</p> <p>Around 8% of cycling trips were of more than 2 km distance and less than 6% of more than 3km distance.</p>
Chinese national standard GB 50413-2007 (quoted in Xu et al. (2016))	Disaster planning, China	<p>Distance to a temporary emergency shelter, may be up to 0.5 km.</p> <p>Distance to a fixed emergency shelter, may be up to 2 km.</p>
Allan (2006, p. 103)	New Zealand tramping (walking) guide	‘As a guideline, an average group will walk: 4 to 5 km per hour on a smooth wide track.’
Ministry of Transport (n.d.)	Transport survey, 2015-18, New Zealand	<p>‘31% of people cycled in the past year’</p> <p>‘16 minutes – the average cycling trip leg’</p> <p>‘1 km – the average walking trip leg distance’</p>

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

#### *4.7.2.2 Proposed LoS – road access*

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

The relative lack in literature of stated emergency, or post-disaster, LoS for transport networks makes it harder to define LoS that have specific references to known standards or guidelines. For the creation of this preliminary framework, the practitioners decided that aspects that were considered key for emergency response and recovery, as relevant to individuals, were for food delivery, water, healthcare and for access to Community Emergency Hubs (locations of community gathering/response following emergencies). For this, the recommendations for ‘the first week’ and ‘the rest of the first month’ at a local level were defined by access between the house and medical centres and Community Emergency Hubs. Additionally, a priority route mapping in the Wellington Region Earthquake Plan (WREP) (Wellington Region Emergency Management Group, 2018) which defines emergency response transport routes required to connect key locations (such as the hospitals and airports) and provide a spine of access to and within the region was available. Within this priority routes mapping, the 2nd, 3rd and 4th

priority routes include coverage of facilities such as supermarkets. A priority route does not, however, guarantee that any particular route will be open by any particular day following an event. Further, the locations of supermarkets, while tending to be covered by the priority routes, are not uniformly located on any particular level of priority route. Rather than be in the detail of defining which facilities or functions are catered for by the access network, instead the framework identifies assumptions on regaining access for priority routes. The balance for the expert panel was between knowing the reality of likely road outages against the need for access to, for example, food and health care following an event. The panel decided that the framework should describe ‘reality’ for most areas, by highlighting that road access will be unavailable in areas, therefore highlighting that access to, for example, the hospital will be impacted in the days following an event. The LoS taken for the road access are shown in Table 10.

#### 4.7.3 Fast Moving Consumer Goods (FMCGs) (for food)

##### 4.7.3.1 *Literature for FMCGs*

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

Minimum food requirements for humans are well researched and understood and are also covered within the Sphere Handbook (Sphere Association, 2018). Although the Handbook gives nutrition requirements of ‘2,100 kCal per person per day with 10–12 per cent of total energy provided by protein and 17 per cent provided by fat’, they note that it is not practical to measure actual energy and nutrient intake during initial assessments, so use proxy indicators. For this reason, the Handbook instead focuses on the measurement of percentage rates of malnutrition, and other factors. Sphere also provides guidance on the locations of provision points, noting that distribution and delivery points should be located at sites accessible, safe

and most convenient for recipients, and recommend the distance from dwellings to final distribution points or markets be less than 5 km.

The UNHCR, UNICEF, WFP and WHO document “Food and Nutrition Needs in Emergencies” gives specific levels of nutrition, including example rations of essentials such as cereals, pulses, oil, meat, sugar etc. along with recommended daily intakes of various vitamins (UNHCR et al., 2002; World Food Programme, 2018). This paper will not investigate further such nutrition specifics, as they have been heavily researched in other contexts, and in any case are unlikely to be a useful measurement in the Wellington region, post-event due to the availability of pre-existing supermarkets (or equivalent) in the region, from which food can be collected, once resupplied. In the Wellington region, rather than addressing nutrition needs, a simpler and probably more effective means of measurement for food availability will be ‘distance to supermarket or food distribution point’. For this, Section 4.7.2 (above) provides an overview of willingness to use active transport (walking and cycling) to access food supplies, including in an emergency.

#### *4.7.3.2 Proposed LoS for FMCGs*

For the preliminary framework, the distance between dwellings and a functioning supermarket is adopted as an appropriate and readily understood measure of food availability. While the Sphere Handbook recommends that the distance between dwellings and final distribution points or markets be less than 5 km, for urban Wellington practitioners considered this distance to be too great as in practice most of urban Wellington is within 2 km of a supermarket. Thus, the framework adopts a 2 km maximum distance between dwelling and supermarket as the target LoS for timeframes beyond the end of the first week through the second and third months (Table 10). For the first week after a major event, the planning assumption, communicated by WREMO to the public, is that residents will have to rely on their stored food reserves, in parallel to the advice for storing water (Wellington Region Emergency Management Office, n.d.-f). This is a set of LoS in which the expert panel had to find a balance between the ‘ideal’ and the practical. Any proposed LoS for walking distances will not be achievable for some members of the community, particularly those who are old, young or have mobility impairments. This issue is addressed in Section 4.7.2, but the key aspect is to note that assistance will be required from others to support those unable to move up to 2km to access

food supplies. A further consideration is that there is a supermarket within 2km of most (over 90%) dwellings in the Wellington metropolitan area. This was considered by the panel to be an acceptable balance for the LoS provided in the framework.

While food availability is key, the ability to cook and to boil water is also a key consideration. In the Wellington region (as in much of New Zealand) there is a popular culture of summer barbeques. Many households have barbeque facilities, normally used with 9 kg liquid petroleum gas (LPG) bottles. These bottles are widely sold, as replacements/refills at supermarkets, fuel stations and other stores. For this reason, and with the obvious connection with food supply, the practitioners decided that the LoS for LPG be similar as for food in terms of distance. The LoS taken for the food sector, and for LPG, are therefore as shown in Table 10.

#### 4.7.4 Fuel

##### *4.7.4.1 Literature for fuel*

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

##### *4.7.4.2 Proposed LoS for fuel*

Following a major event, road access is likely to be unavailable for ‘days to weeks’ in parts of the region (Wellington Lifelines Group, 2019). The restoration of the fuel supply chain will require a functioning port facility and fuel storage depots, road access, power supply to the

service station and, for electronic payments a functioning telecommunications network. Therefore, the LoS for fuel availability in the framework focusses on rationing existing stored fuel until the fuel supply chain is fully functioning. The LoS is that existing fuel stored in tanks at service stations be rationed to critical customers such as emergency services until the end of the first month. For the second and third months, the LoS goal is that priority service stations across the region are functioning (Table 10). Priority service stations are listed within Wellington Region emergency response plans; they are not a guarantee of fuel availability but provide an understanding of which service stations will first be supported for restoration of services by the emergency response partners. The expert panel considered that balance was created in the LoS by prioritising critical functions in response and recovery.

#### 4.7.5 Power (electricity)

##### *4.7.5.1 Literature for power*

Kinn and Abbott (2014), who investigated the role that the provision of electricity held in resilience literature, found that, in their search of 4,127 studies on resilience and disaster cases, only 3.9% had key words connected to electricity. This was mirrored in this literature review where there was comparatively little literature found on the resilience of power supply or power requirements in disaster response compared to other infrastructure sectors. The above paper also outlined the importance of a power supply to keep critical facilities such as hospitals functioning. In a similar vein, May (2017) notes that in Puerto Rico, following Hurricane Maria, around two months after the impact of the hurricane ‘...recovery efforts focussed on restoring power to critical institutions such as hospitals, fire stations, and water treatment plants, and that more than 50 percent of the island’s 3.4 million residents were still without power’. The infrastructure effort in that case appeared to be on assisting priority sites to function.

Several examples were found that quantified the impacts of power outages on critical facilities. Laher et al. (2019) note that ‘for every day with a power outage lasting more than 2 hours, hospital mortality has been estimated to increase by 43%’. They note that various medications and vaccines need to be stored within specific temperature ranges, an issue that will be particularly relevant to hospitals and pharmacies. These authors, and (Dishel, n.d.; Laher et al.,

2019) make recommendations for the provision and maintenance of alternative power sources such as generators, with adequate fuel supplies available, or alternative energy sources such as wind or solar.

With respect to continuity of power supply and food safety, Kosa et al. (2012) reported that two days after a power outage in 2003 in New York, there was a statistically significant increase in patient visits for diarrheal disease to medical facilities and recommended that public health educators and educators tailor information on emergency preparedness to maintaining food safety during power outages. The Office of Personnel Management (2003) recommends that during a power outage, refrigerator and freezer doors be kept closed as much as possible.

None of the above literature gave measurable standards for the post-disaster provision of power, nor does the Sphere Handbook (Sphere Association, 2018) provide standards for power supply.

#### *4.7.5.2 Proposed LoS for power*

Following an earthquake cause by rupture of the Wellington fault, there is unlikely to be a networked power supply available for up to six months within the Wellington region (Wellington Lifelines Group, 2019). The preliminary framework focusses only on emergency response provision, noting that power will be required for priority sites such as hospitals and police stations until the end of the first month. The framework is not specific on the means of supply of electricity to those facilities, meaning that if they are fitted with generators and can be supplied fuel, or supplied from other alternative sources, they could be powered without connection to the network.

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

functions and for charging telecommunications devices provided a balanced planning emergency LoS.

#### 4.7.6 Telecommunications and broadcasting

##### *4.7.6.1 Literature for telecommunications and broadcasting*

Key information on resilience (including response and recovery) aspects of the telecommunications and broadcast sectors is provided by the International Telecommunications Union (ITU), which is a United Nations specialised agency for information and communication technologies. As an aggregation of key information, the Technical Report on Telecommunications and Disaster Mitigation, ITU-T Focus Group on Disaster Relief Systems, Network Resilience and Recovery (International Telecommunication Union, 2013) and the Broadcasting for public warning, disaster mitigation and relief (International Telecommunications Union, 2017) provide excellent resources on the provision of emergency telecommunications and broadcast services. The ITU-T (2013) report notes that the loss of power affecting telecommunications services has been a significant factor in some disasters. Having a secure networked power supply, or access to alternatives such as generators, was highlighted as a key consideration for continued operations. The above report on telecommunications focuses on case studies gathered from the past decades when there was a greater use of landline (fixed) telephones. The greater reliance on cell phones in the 21st century creates different issues for telecommunications services provision.

The International Telecommunication Union (2013) report also notes that to reduce telecommunications network congestion on calls (in the initial flush of response), various measures can be taken including “reassigning network resources to telephony” to allow people to call each other and “reducing call quality”. This would mean prioritising telephone calls over data (i.e. internet) services. Further, priority can be given to the ‘first responders and for emergency calls’ (section 6.6.2.1). Again, this supports the concept of giving priority to some key facilities in a response such as those that provide emergency services.

The above report also notes two key aspects: that disaster information services should be available for all sectors of society, including the vulnerable (noted as deaf, blind, illiterate, old, young, visitors, international visitors and roamers), and also that while buried infrastructure is vulnerable to damage in a hazard event, radiocommunications are not susceptible to such

damage. Therefore, above-ground networks will provide greater resilience to some hazards. Taking these issues together, the provision of broadcast services (such as VHF radio) can provide information to many people, including most sectors of society, in an emergency. Separately, the Communications Security, Reliability and Interoperability Council, which is an advisory committee that is part of the Federal Communications Commission, an independent US government agency published a report ‘Working Group 2B MSRC Best Practice Update’, which includes a ‘Local Radio Station Model Disaster Recovery Plan & Incident response manual’. This includes the statement that ‘keeping all aural and data services on the air is most desirable, ensuring that the aural services remain on the air to serve the community is an absolute necessity’ (Communications Security Reliability and Interoperability Council, 2011, p. 11). This aligns with the ITU statements on the reliability of above-ground services, with the implication that the broadcast of VHF radio services should be of the highest priority. Broadcast can be a key means of disseminating information to a wider community.

#### *4.7.6.2 Proposed LoS for telecommunications and broadcasting*

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

The telecommunications and broadcast sectors are complex in their nature, with technologies evolving quickly, and (in New Zealand) a relatively complex telecommunications network provided by various owners/operators that provide a range of interdependent services. For this reason, the preliminary framework for telecommunications could have been relatively complex in terms of the kinds of device that were recommended for use. Instead, the practitioners

decided that the ‘starting point’ LoS focus on the intended outcomes of the telecommunications use. In a hierarchy, the following outcomes were targeted: for the self-sufficiency phase, the ability to send and receive text messages, as this allows information to be shared, but causes less congestion issues on telecommunications networks (International Telecommunication Union, 2013). For the basic functionality phase, the ability to have some level of use of mobile data was chosen as a level of service, as this allows individuals to use social media to communicate with their family and friends. For the moderate functionality phase, the ability to use voice call systems was recommended as an ‘end point’ for a functioning telecommunications system in an emergency.

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

Regarding broadcast recommendations, as above, the availability of power supply at the household level means that radio services such as FM radio would provide the best means of broadcasting public information, if radios are powered by batteries. The availability of television services is therefore recommended for the ‘significant functionality’ phase of recovery. The expert panel considered that the provision of FM radio (for broadcast information) and the availability of basic telecommunications functions was a fair balance between the desirable (functioning TV and phone call capability) and the likely reality of modelled outages. The LoS taken for the telecommunications and broadcast sector are as shown in Table 10.

#### 4.7.7 Sanitation

##### 4.7.7.1 *Literature for sanitation*

As for the water sector, the Sphere Handbook (Sphere Association, 2018) provides well-researched and referenced guidance and standards for sanitation provision. The standards include the statement (p92):

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

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

The Centres for Disease Control and Prevention (n.d.) and Tratschin and Spuhler (n.d.) provide guidance on a range of potential emergency sanitation solutions during times of wastewater system outages. Not all the solutions will be viable in all settings. For instance, chemical toilets require collection and disposal of the waste, which in turn require a functioning road network and wastewater treatment plant. Other solutions include bucket latrines, trench latrines and communal or family latrines.

For New Zealand, the public advice on the ‘Get ready, get thru’ website (National Emergency Management Agency, n.d.-c) includes the following statement on making an emergency toilet: “Use watertight containers such as a rubbish bin or bucket, with a snug-fitting cover.” The use of watertight containers is recommended, presumably for use within the house, with the resulting waste being disposed of outside the home.

Following the Canterbury sequence of earthquakes commencing in 2010, discussions were held at Christchurch City Council on LoS for water and wastewater infrastructure. These discussions led to suggestions on how a level of service could be defined. An example level of service was that within 48 hours of an event, 85% of domestic premises should have a wastewater connection, and that within 2 weeks of an event 80% of effluent should reach the treatment plant. As of 2021, there is no record in the literature of the above LoS being adopted by the council.

While other studies are available, these tend to be applicable to low-income regions (Harvey et al., 2002; Mwambu, 2013). This means that evidence-based advice for New Zealand is less available, and no standards are given regarding the delivery of services.

In addition to the provision of a means of safe disposal of excreta, which is one aspect of sanitation, water is required for handwashing (Cairncross & Feachem, 1993). Consideration of water provision is included in the water section, above.

#### *4.7.7.2 Proposed LoS for sanitation*

In a large earthquake, the wastewater networks will suffer high levels of damage, particularly in areas with a high liquefaction hazard and areas of slope instability, and as a result of co-seismic subsidence and horizontal movements. Therefore, the disruption to networked wastewater services, in some areas, will be for a matter of months or years (Wellington Lifelines Group, 2019). For this reason, the framework focusses on alternative means of the disposal of sanitation waste.

While a good deal of research, from a variety of contexts and understandings, exists for some infrastructure sectors, the provision of emergency sanitation in a developed urban context is less well understood (Smith, M. Water, Environment and Development Centre, UK, personal communication, July 11, 2019). For the Wellington region, two references provide context on the risk of wastewater system failure (Stewart C et al., 2019, April 4-6) and challenges and opportunities to finding an emergency sanitation solution for the region (Brenin et al., In press). This appears to be an area ripe for further research. The Wellington Region Emergency Management Office, Wellington Water and the Wellington Region Public Health organisation collaborated on a project on emergency sanitation, with self-sufficiency up to ‘day seven’, then options for basic sanitation functionality (Mowll, Stewart, et al., 2022). The solutions recommended in that plan are relatively basic, including the use of two buckets for emergency sanitation, one bucket for ‘wee’ (urine), one for ‘poo’ (faeces) but allow for a variety of potential solutions at the household level and are adopted in the preliminary framework (Table 10). This LoS acknowledges that, while the desired LoS may be higher, the most realistic scenario, following a major event, is that households will have to make their own sanitation arrangements for a period following a major event. This LoS is therefore in line with the basic levels outlined in the literature, which will not be familiar to many in the community in the high-income context of the Wellington region.

## 4.7.8 Shelter

### 4.7.8.1 *Literature for shelter*

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

For shelter standards, again the Sphere Handbook provides guidance, including some post-crisis settlement scenarios for both non-displaced and displaced populations and may be considered a source of best practice. (Sphere Association, 2018, p. 243). These scenarios include owner-occupied accommodation or land, rental and hosted arrangements etc.

### 4.7.8.2 *Proposed LoS for shelter*

The level of service used in the preliminary framework combines the wording used in the Sphere Handbook (Sphere Association, 2018) with advice given by WREMO for emergency preparedness in the Wellington region (Wellington Region Emergency Management Office, n.d.-f). Acknowledging that in post-event Wellington many houses and apartments may be uninhabitable in a major emergency (Cousins, 2013), the preliminary framework is relatively open regarding the possible accommodation possibilities.

The overall preliminary framework for planning emergency LoS for the Wellington region is presented in Table 10, followed by a discussion of assumptions and caveats.

## 4.8 The overall framework

The overall framework is presented below as a compilation of the previously discussed individual preliminary LoS. As demonstrated in the infrastructure-specific parts of Section 4.7, the framework is intended to be a balance between the desired LoS and what is considered practical in the Wellington region following a major event. The holistic framework is:

**Table 10: Wellington region -planning emergency levels of service<sup>i</sup> - PRELIMINARY FRAMEWORK**

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

## Assumptions/caveats:

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

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<sup>i</sup> These standards do not apply in ‘red zones’ or cordoned areas where people are assumed not to be sheltering.

<sup>ii</sup> Taken from Sphere Handbook, section 2.1, page 107: <https://spherestandards.org/handbook/editions/>

<sup>iii</sup> Taken from World Health Organisation: [https://www.who.int/water\\_sanitation\\_health/emergencies/qa/emergencies\\_qa5/en/](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).

<sup>iv</sup> Taken from Wellington Water’s ‘80-30-80’ strategy

<sup>v</sup> See Wellington Region Earthquake Plan (WREP) of December 2018 for WREMO for priority routes (Annex F).

<sup>vi</sup> Restrictions may be in place for non-emergency vehicles (to manage safety issues).

<sup>vii</sup> Distribution points are listed in the Wellington Region Earthquake Plan (WREP) of December 2018 from WREMO. See Appendix G1.

<sup>viii</sup> The Sphere Handbook (item 6.3) has a target of less than 5km. <https://spherestandards.org/handbook/editions/>

<sup>ix</sup> For a list of priority sites, see WeLG/WREMO/WELA ‘lifelines response priorities: 8 February 2019’

<sup>x</sup> As included in the WeLG/WREMO/WELA Key Utility Sites document of 2016.

<sup>xi</sup> See <https://getthru.govt.nz/radio-stations-to-listen-to> for a list of the priority radio stations

<sup>xii</sup> See <http://transition.fcc.gov/pshs/docs/csric/WG2B-MSRC-Best-Practice-Update-Final-Report.pdf> section titled ‘Vulnerability Assessment Guidelines’.

<sup>xiii</sup> See Mowll et al. (2022)

<sup>xiv</sup> See <https://spherestandards.org/handbook/editions/> for additional information/direction. Assumes staying within own home or property.

## 4.9 Assumptions, caveats and limitations

### 4.9.1 Key assumptions and caveats

A key consideration covered by the Sphere Handbook is the provision of services to those less able to provide for themselves such as the very young, the elderly or disabled. The Handbook (Sphere Association, 2018, pp. 10-12) notes that “individuals and groups within a population have different capacities, needs and vulnerabilities, which change over time”. The preliminary framework proposed in this paper is relatively simplistic in its approach and does not cater for individual needs. However, welfare networks do exist, both formally, through their provision by local authorities and local non-government organisations, and also through the informal support networks of family, friends and by local neighbourhood networks. For this reason, a very broad statement has been added to the framework noting that:

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

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

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

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

## 4.9.2 Limitations

As noted in Section 4.9.1, there are some clear limitations in the applicability of this framework for vulnerable individuals, where a similar approach is taken to the Sphere Handbook (Sphere Association, 2018) in proposing a level of service, where (p7):

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

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

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

## 4.10 Discussion and conclusions

Regarding frameworks bringing together response and recovery targets, the NIST-related documents (Oregon Seismic Safety Policy Advisory Commission, 2013; Poland, 2008; Washington State Seismic Safety Committee Emergency Management Council, 2012) use a framework which does define the recommended LoS for their own areas, alongside estimates of when infrastructure is assessed to be operational following an event. These examples are proof that LoS can be developed and publicised at city and state level. The LoS in these documents tend to be aimed at the infrastructure provider rather than the end-user communities,

for example giving LoS for highways and airports rather than when food will be available at supermarkets.

The Sphere Handbook (Sphere Association, 2018, p. 9) details how human rights drive the standards created within that document. What is less defined is how these standards translate to a high-income context, an argument that Bross et al. (2019) also use, noting that global minimum standards are ‘hardly applicable’ to high income countries. Power, broadcast and telecommunications services do not immediately appear to be essential for supporting life and are more of a high-income country ‘requirement’. However, in high-income countries, electricity is required to power health facilities and emergency services and for enabling service stations to operate, which in turn can provide fuel for emergency generators at key facilities such as the hospitals, police stations and broadcast sites. The provision of such services necessarily span a mix of human needs across food and water supply and the provision of more specialist services such power to a medical facility. This is where a context-specific set of standards, or potentially ‘emergency levels of service’ may be desirable, for the utilities and emergency response agencies to plan for outages.

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

The framework presented in here is preliminary. At this stage it is not a viable working document ready for adoption by the utilities, the emergency planning community or individuals within the region but is intended to provide a high-level basis for discussion with the utilities and key stakeholders to move towards an operationalised framework. It is not intended that following an event that rigorous measures be taken to establish whether these LoS were achieved, or not. In fact, such moves would be considered counter-productive to the intentions of the framework as these could make the respective parties sensitive to the possibility that they will be measured (or perhaps judged) by specific instances of availability of services, post-event. The next step of development of the preliminary framework is to research, with key stakeholders including the critical infrastructure providers, how the LoS may be improved, appropriate to the respective sectors. Similar frameworks could be created at a high level by

similarly placed practitioners in other regions of New Zealand, or internationally, for other contexts or regions.

## **5 Paper 2: Infrastructure planning emergency levels of service for the Wellington region, Aotearoa New Zealand – an operationalised framework**

This section takes forward the preliminary framework and, based on interviews with experts and a workshop, presents an operationalised framework of ‘planning emergency levels of service’. The workshop held for this research included members of the Wellington Lifelines Group (a grouping of critical infrastructure entities in the Wellington region) who as well as providing input into the framework, confirmed that the framework should be adopted by the group (i.e., as an operationalised framework), and that it could be publicly released, through the publication of this section (as an academic paper). The paper additionally summarises features of the framework that were discussed in interviews, including interdependencies, the relationship between the framework and a hazard event and how engagement with critical infrastructure entities was key to its creation and adoption.

The statement of contribution sheet for this paper is in Appendix 1 of this thesis. The *Bulletin of the New Zealand Society for Earthquake Engineering* published this paper.

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## 5.2 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.

## 5.3 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 (Wellington Lifelines Group, 2012, 2019; Wellington Region Emergency Management Office, 2019). Other key hazards that may impact the Wellington region include tsunamis, flood and pandemic (Wellington Region Emergency Management Office, 2019). 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 (United Nations Economic and Social Council, 1999; United Nations General Assembly, 2010), 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 (United Nations General Assembly, 1948). The Sphere Association (Sphere Association, 2018) 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, Becker, et al. (2022). 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 (2003), PELOS for the other sectors (energy, transport, telecommunications) are less well developed. The preliminary framework proposed by Mowll, Becker, et al. (2022) 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) (National Emergency Management Agency, 2016). 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).

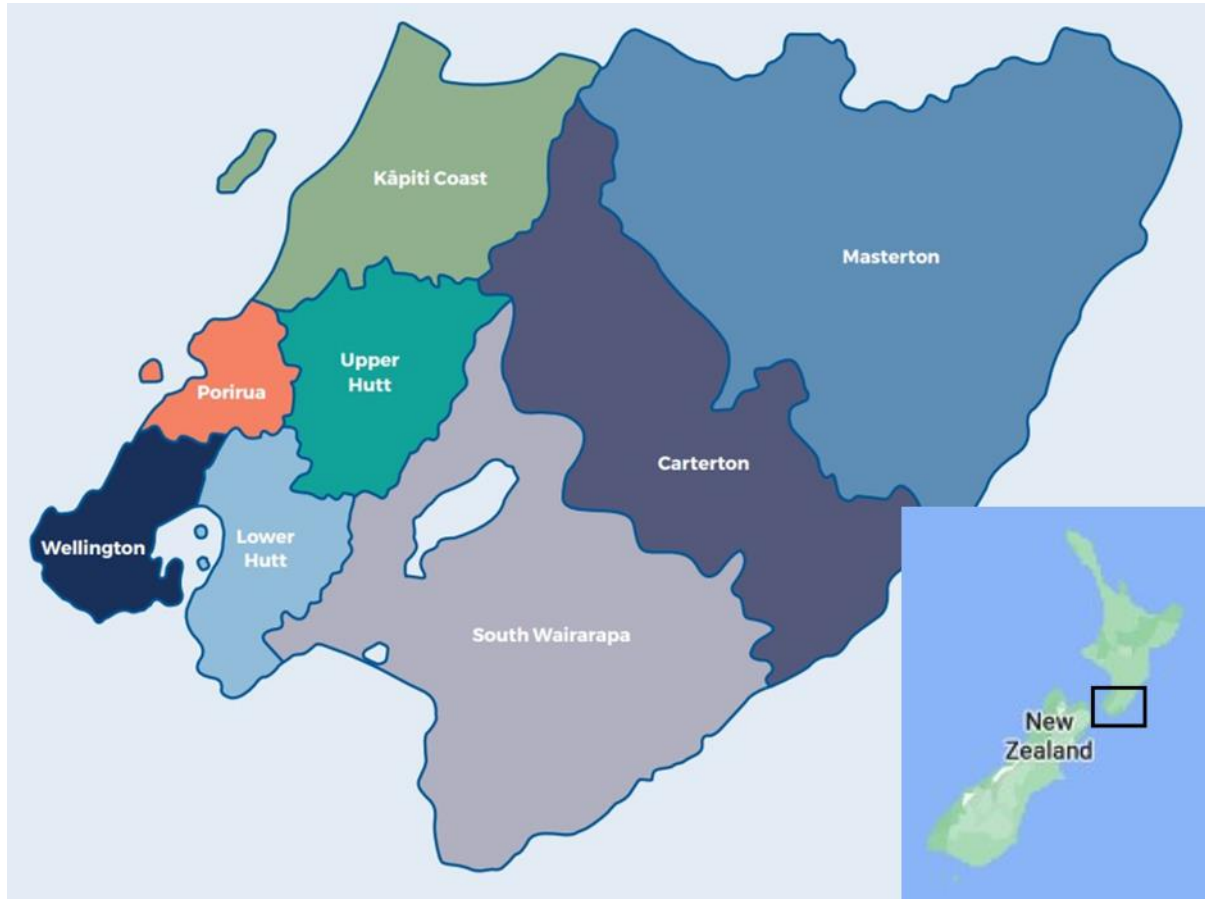


Figure 4: Local councils comprising the Wellington region, Aotearoa New Zealand

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 (Mowll, Becker, et al., 2022) 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.

## 5.4 Methodology

### 5.4.1 Preliminary work

The theoretical foundation of PELOS was documented by Mowll, Becker, et al. (2022). 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.

#### 5.4.2 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 (2002), New Zealand's key emergency management legislation (2023). 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.

#### 5.4.3 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 (McNiff, 2013) 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.

#### 5.4.4 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.

### 5.5 Operationalised framework

The updated, operationalised framework is presented in Table 11.

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.

**Table 11: Wellington region - infrastructure planning emergency levels of service - 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
<b>Water</b>	Minimum of 3 litres per person per day <sup>xv</sup> , but recommended 20 litres per person per day, as stored at homes by individuals	15-20 litres of water per person per day <sup>xvi</sup> within 1km of the house	80% of supply of potable water to 80% of customers <sup>xvii</sup>	Full functionality towards a 'new normal'.
<b>Roading<sup>xviii</sup></b>	Limited road use – only priority 1 routes <sup>xix</sup> or immediate alternates are open to emergency vehicles. Walking and cycling access to local medical centres and to Community Emergency Hubs is available.	<p>Priority 1 routes are open and managed<sup>xx</sup>, 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.</p> <p>Road access is available between dwellings and local medical centres and Community Emergency Hubs and between water stations and distribution points to enable water<sup>xxi</sup> to be distributed.</p>	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'.
<b>Food and LPG</b> (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 <sup>xxii</sup> within 2km <sup>xxiii</sup> 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'.
<b>Fuel<sup>xxiv</sup></b>	Diesel only: where access, power and resources allow, strict rationing <sup>xxv</sup> 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 <sup>xxvi</sup> , strict rationing <sup>xxvii</sup> to priority list of users (e.g., emergency services) using fuel storage in place at time of emergency and any immediate re-supply	<p>Ability to transfer fuel from berth (at port) to tank farm(s).</p> <p>Priority, or selected, service stations are operating.</p>	Full functionality towards a 'new normal'.
<b>Power (electricity)</b>	Households <sup>xxviii</sup> use from local sources <sup>xxix</sup> and response priority sites <sup>xxx</sup> (including hospitals and key facilities) and medical centres, pharmacies and supermarkets use own pre-arranged power supply for essential functions.	<p>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.</p> <p>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.</p>	<p>Power to response priority sites and key utility sites<sup>xxxix</sup>.</p> <p>Ability to charge phones and tablets at a location within a local area such as a local Community Emergency Hub.</p>	Full functionality towards a 'new normal', including street lighting <sup>xxxiii</sup> .

<b>Telecommunications</b>	EXAMPLE: Access to mobile data (via wireless) and untethered broadband at defined locations such as at Community Emergency Hubs <sup>xxxiv</sup> . (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.	
<b>Broadcast</b>	FM radio – Priority Stations <sup>xxxv</sup> : fully operational <sup>xxxvi</sup>	Fully functional for priority radio stations, no TV	Fully functional for priority radio stations, no TV	Full functionality towards a 'new normal'.
<b>Sanitation</b>	Self-sufficiency by the community for sanitation needs (long-drops, two buckets or similar (no council service)).	Service, according to the 'two buckets' plan <sup>xxxvii</sup> .	Service, according to the 'two buckets' plan.	Full functionality towards a 'new normal'.
<b>Solid waste</b>	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'.
<b>Natural gas</b>	Zero level of service	Critical customers re-supplied by isotainer and necessary equipment, where customer has made own arrangements.	Main pipelines re-commissioned <sup>xxxviii</sup> . Some critical customers are re-connected. Some suburbs have pipelines re-commissioned.	All customers re-connected <sup>xl</sup> .
<b>Port</b>	Freight: zero level of service for days 0 to 7.	Freight: 450 TEUs ('Twenty foot Equivalent Units', or 20ft containers), or equivalent, per day <sup>xli</sup> .  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'.
<b>Airport</b>	The Airport should be able to operate a 1,200m long runway within 2 days of a major event <sup>xlii</sup> .			If specialist equipment and material is available, a length of runway sufficient to land and take off civilian jet aircraft will be available <sup>xliii</sup> .
<b>Shelter</b>	Shelter within own property or with immediate support network or at mass temporary accommodation sites. <sup>xliiv</sup>		Shelter within own property, with immediate support network or at alternative site.	

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- <sup>xv</sup> Taken from Sphere Handbook, section 2.1, page 107: <https://spherestandards.org/handbook/editions/>
- <sup>xvi</sup> Taken from World Health Organisation: [https://www.who.int/water\\_sanitation\\_health/emergencies/qa/emergencies\\_qa5/en/](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](https://spherestandards.org/handbook/editions/ (15 litres) and from) Wellington Water’s ‘80-30-80’ strategy (20 litres).
- <sup>xvii</sup> Taken from Wellington Water’s ‘80-30-80’ strategy
- <sup>xviii</sup> Following an event, assessments of damage may change priorities.
- <sup>xix</sup> 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.
- <sup>xx</sup> Restrictions may be in place for non-emergency vehicles (to manage safety issues).
- <sup>xxi</sup> 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/>
- <sup>xxii</sup> Distribution points are listed in the Wellington Region Earthquake Plan (WREP) of December 2018 from WREMO. See Appendix G1.
- <sup>xxiii</sup> The Sphere Handbook (item 6.3) has a target of less than 5km. <https://spherestandards.org/handbook/editions/>
- <sup>xxiv</sup> The fuel line is relevant as long as diesel is used for powering generators, earthmoving machinery and delivery trucks.
- <sup>xxv</sup> 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>
- <sup>xxvi</sup> This includes resources to inspect and re-open service stations, and the resources required to operate them.
- <sup>xxvii</sup> 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>
- <sup>xxviii</sup> Including medically dependant people located at home.
- <sup>xxix</sup> Example, household solar panels, or generators.
- <sup>xxx</sup> For a list of priority sites, see WeLG/WREMO/WELA ‘lifelines response priorities: 8 February 2019’
- <sup>xxxi</sup> As included in the WeLG/WREMO/WELA Key Utility Sites document of 2016.
- <sup>xxxii</sup> Power supply (from the grid) requires generation and national transmission assets to be operational.
- <sup>xxxiii</sup> 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.
- <sup>xxxiv</sup> assuming the CEH’s system has capacity
- <sup>xxxv</sup> See <https://getthru.govt.nz/radio-stations-to-listen-to-for-a-list-of-the-priority-radio-stations>.
- <sup>xxxvi</sup> See <http://transition.fcc.gov/pshs/docs/csrc/WG2B-MSRC-Best-Practice-Update-Final-Report.pdf> section titled “Vulnerability Assessment Guidelines”.
- <sup>xxxvii</sup> 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/>
- <sup>xxxviii</sup> Natural gas supply from a reticulated network requires national transmission assets to be operational.
- <sup>xxxix</sup> 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.
- <sup>xl</sup> All customers must have a gas professional re-connect supply to network.
- <sup>xli</sup> 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.
- <sup>xlii</sup> Weather and navigation instrumentation constraints may impact operations.
- <sup>xliii</sup> Weather and navigation instrumentation constraints may impact operations.
- <sup>xliv</sup> See <https://spherestandards.org/handbook/editions/> for additional information/direction. Assumes staying within own home or property.

## 5.6 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.

### 5.6.1 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.

### 5.6.2 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 (New Zealand Government, 2020), 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 (Wellington Water, 2018b), none of the internal PELOS work had been published.

### 5.6.3 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 (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 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.

#### 5.6.4 Hazard event for the framework

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 (National Emergency Management Agency, 2018) 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.

#### 5.6.5 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.

#### 5.6.6 Other services

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.

### 5.7 Results – sector-specific results

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.

### 5.7.1 Water

Due to the information campaigns on the storage of water prior to an event carried out by both Wellington Water and WREMO (Wellington Region Emergency Management Office, n.d.-c, n.d.-e, n.d.-f; Wellington Water, n.d.-b), 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’ (Wellington Water, 2018b). 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.

### 5.7.2 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) (Waka Kotahi New Zealand Transport Agency, n.d.-b, n.d.-c) 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.

### 5.7.3 Fast Moving Consumer Goods (FMCGs) (and Liquefied 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 (Herriges, 2019). 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.

#### 5.7.4 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 (2019).

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.

#### 5.7.5 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”.

### 5.7.6 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 (New Zealand Lifelines Council, 2020). 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” (Wellington Region Emergency Management Office, n.d.-b). 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.

#### 5.7.7 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 (Mowll, Stewart, et al., 2022) 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.

### 5.7.8 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’ (National Emergency Management Agency, 2016). 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.

### 5.7.9 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 (National Emergency Management Agency, 2018). 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 (National Emergency Management Agency, 2018), 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.

### 5.7.10 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 (Wellington Region Emergency Management Office, n.d.-d). 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 1,200 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.

### 5.7.11 Gas

There were no PELOS included in the preliminary framework for natural gas (mainly methane) supply. Several interviewees (6, 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 (Wellington Lifelines Group, 2019). 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.”

## 5.8 Interdependencies

The issue of interdependencies – how critical infrastructure sectors rely on each other for their successful operation (Moore et al., 2021, December 12-15; New Zealand Lifelines Council, 2020; Oster et al., 2021, November 8-9; Wellington Lifelines Group, 2019) – 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 Table 12.

Table 12: logic for key interdependencies

	Operationalised PELOS	Associated PELOS	Interdependencies?
<b>Food:</b> 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 (2019) for earthquake example).	As such, no interdependency issues.
<b>Food:</b> 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.
<b>Fuel:</b> 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.
<b>Fuel:</b> 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.
<b>Water:</b> 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.
<b>Water:</b> 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.

## 5.9 Discussion

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

### 5.9.1 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.

### 5.9.2 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.

### 5.9.3 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 (Wellington Region Emergency Management Office, 2019), 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.

#### 5.9.4 Future research required

This 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 (Sphere Association, 2018) 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 (National Emergency Management Agency, 2020) 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.

#### 5.10 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 Wellington Lifelines Group (2019), 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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## **6 Paper 3: Creating a ‘Planning Emergency Levels of Service’ framework – a silver bullet, or something useful for target practice?**

This section provides comment on the theoretical foundations of the concept of planning emergency levels of service and explains the process through which the operationalised framework was created. It then explores five key themes related to the framework, namely: interdependencies, 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. The intention of this section is to outline how organisations in other locations could follow a similar process in defining their own planning emergency levels of service.

The statement of contribution sheet for this paper is in Appendix 1 of this thesis.

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## 6.2 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.

## 6.3 Introduction

### 6.3.1 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 (2010). While the term, and use of levels of service is well understood in the management of infrastructure, Mowll, Becker, et al. (2022) 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 (Oregon Seismic Safety Policy Advisory Commission, 2013; Poland, 2008; Washington State Seismic Safety Committee Emergency Management Council, 2012), which led to the creation of the NIST Guide (National Institute of Standards and Technology, 2016) 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 (2003) and the Sphere Association (2018), 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' (Wellington Water, 2018b, p. 34). 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 (Sphere Association, 2018; World Health Organization, 2003) 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 organisations 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 (n.d.-a, p. 1). 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 (2015)). These examples 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' (Blagojević & Stojadinović, 2022; Capacci et al., 2022; Rohit Ranjan et al., 2022), 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' (United Nations Office for Disaster Risk Reduction, n.d.). Most other OECD countries and bodies also use the term 'critical infrastructure' for example the European Union (2008), Australia (Australian Government, 2015) and the USA

(U.S. Department of Homeland Security, 2013). 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 (Wellington Lifelines Group, n.d.), 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 (2019) 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, minimise or eliminate or mitigate risks (Australian Government, 2018). In New Zealand, the Civil Defence Emergency Management Act No 33 (2002) 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 (Standards New Zealand, 2004), 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 (Mowll, Becker, et al., 2022), into an operationalised PELOS framework, (Mowll, Becker, et al., 2022) 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

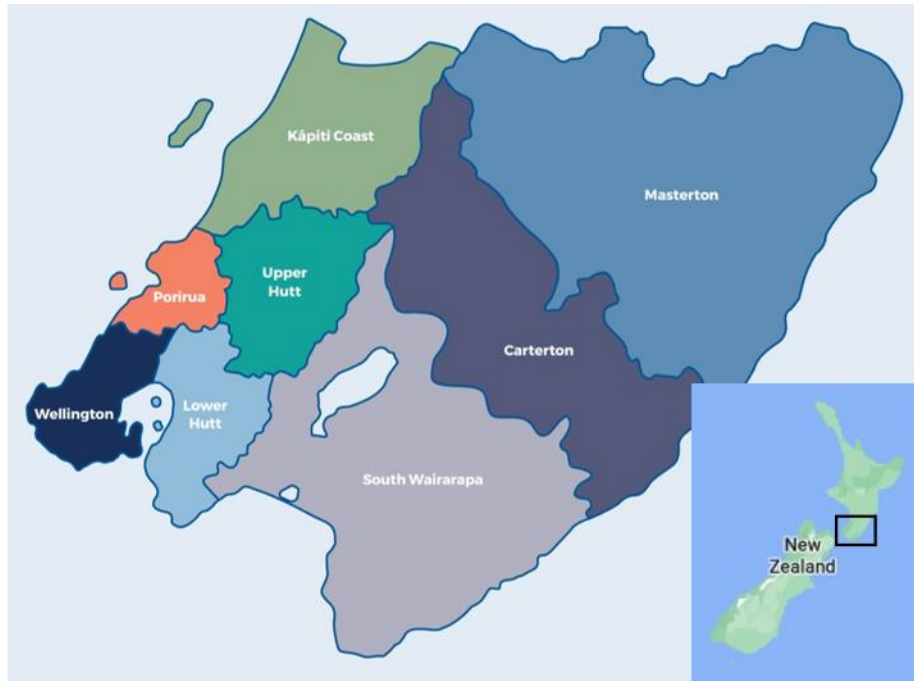
from 1km away, and other community members that will struggle to interface with the PELOS;

- 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 a operationalised one is covered in Section 6.4. The key issues and themes (noted above) are explored in Section 6.5. Discussion points and engagement issues are covered in Section 6.6, with conclusions drawn in Section 6.7.

### 6.3.2 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 Figure 5).



*Figure 5: Local councils comprising the Wellington region, Aotearoa New Zealand*

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 (Wellington Lifelines Group, 2012, 2013, 2019). The aforementioned studies focus on a major earthquake impacting the region (for the 2019 study, specifically a rupture of the Wellington fault), although the (Wellington Region Emergency Management Office, 2019) 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 (Wellington Lifelines Group, 2019) 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’ (Wellington Region Emergency

Management Office, 2019), 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” (National Emergency Management Agency, n.d.-b) 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 (Civil Defence Emergency Management Act No 33, 2002). 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 6.5.4.

## 6.4 Creating a PELOS framework: methodology and process

### 6.4.1 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 (McNiff, 2013) sees that action researcher/practitioners work in environments with other practitioners in which negotiation is required to progress, and where 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 6.6.5.

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 (2002)) sectors of energy, telecommunications, transport and water. The lead author holds working relationships with the relevant organisations, again matching the action research methodology. Details of the interviews and analysis methods are given in Sections 6.4.4 and 6.4.4.2.

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

#### 6.4.2 Process taken to create the PELOS framework

The process taken in creating a PELOS framework in the Wellington region is summarised in Figure 6. The bands across the diagram (preliminary work, engagement, decision-making, finalisation and release) are taken as the main headings for the following parts of this section.

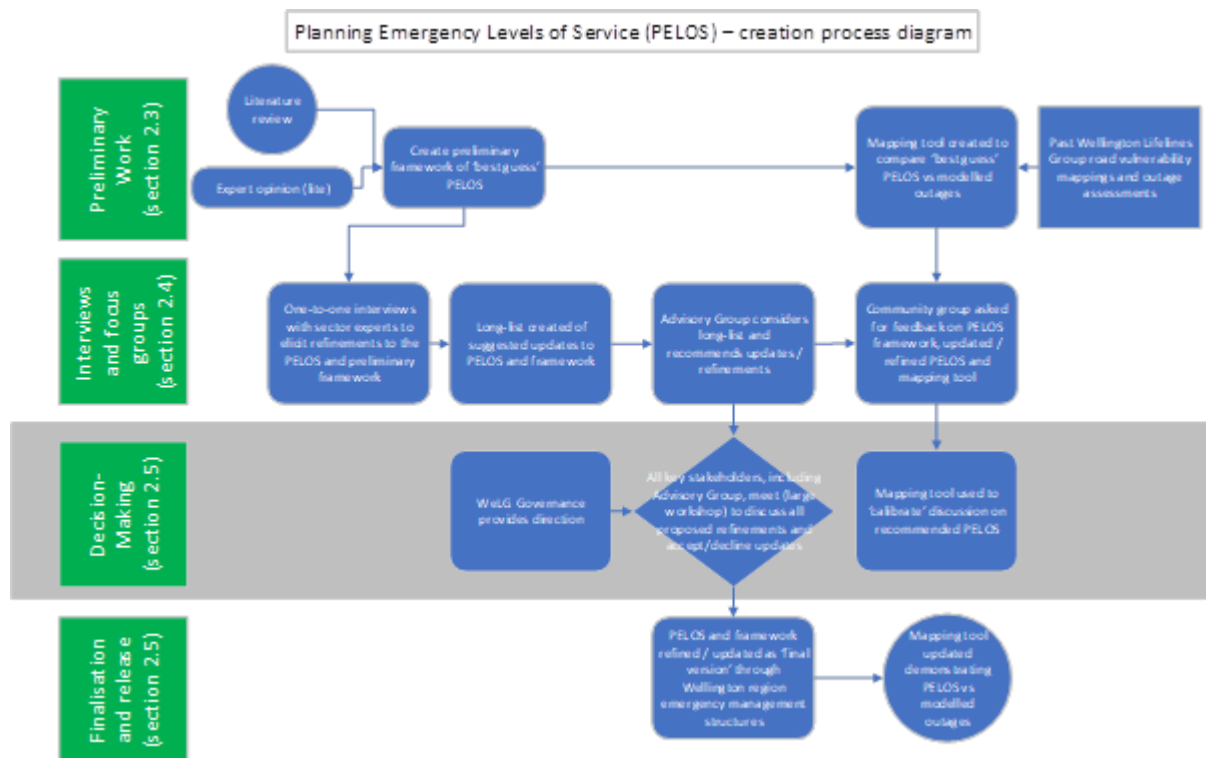


Figure 6: PELOS creation process diagram

The National Institute of Standards and Technology (2016) [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 6.3.1. 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.

### 6.4.3 Preliminary work

#### 6.4.3.1 *Literature review*

The first step of the process of creating a framework of PELOS was a literature review. As outlined in Section 6.3.1, the literature review for this research, detailed by Mowll, Becker, et al. (2022), 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.

#### 6.4.3.2 *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

litres 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 6.5.3.2.

#### *6.4.3.3 Create a preliminary framework*

As detailed by Mowll, Becker, et al. (2022), 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 (Wellington Lifelines Group, 2019) and balanced against ‘best guess’ human needs (as detailed in Section 6.4.3.2). 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.

#### *6.4.3.4 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 operationalised 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 (Wellington Lifelines Group, 2019), 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.

#### 6.4.4 Interviews and focus groups

##### 6.4.4.1 *Conduct interviews*

The creation of the operationalised 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 6.4.1, the lead author has a role within emergency management, and 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 (McNiff, 2013) therefore allowed for the integration of those two aspects together as a coherent methodology for conducting this research.

Staff from a wide set of organisations, 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 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, Becker, et al. (2022), for background information/context. The remaining three interviews were also semi-structured, but held with two or three interviewees, where the relevant organisations' 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 organisations 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 summarised in Table 13.

*Table 13: interviewees - number and sectors*

<b>Sector</b>	<b>Number of interviewees*</b>	<b>Group or individual</b>
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.

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 minimised the work required in the workshop and ensured that each suggestion was allowed full consideration by emergency management professionals.

#### *6.4.4.2 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 14. NVIVO is a software tool used by qualitative researchers to order and analyse 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 organisations or personal preparedness.

Table 14: Coding nodes and references captured

<b>Node</b>	<b>Number of files (interviewees commenting)</b>	<b>Number of references captured (times that this code was referred to)</b>
<b>General issues:</b>		
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
<b>Sector-specific issues:</b>		
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
<b>Process and release issues:</b>		
Visualisation of outputs/outages to be released?	28	28
Publicly release the framework?	29	29

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.

#### 6.4.5 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 (Wellington Region Emergency Management Office, 2019). 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 finalise 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, 'operationalised' 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 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 finalised through agreement within the Wellington Lifelines Group Steering Committee, and through the emergency management governance processes of the Wellington region.

## 6.5 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.

### 6.5.1 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 analysing infrastructure interdependencies in detail, for example Moore et al. (2021, December 12-15), Oster et al. (2021, November 8-9) and Macaulay (2009). For the creation of the operationalised 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 (Wellington Lifelines Group, 2019). 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 operationalised 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's a start on the journey” (interview 11).

### 6.5.2 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, Becker, et al. (2022), 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 litres of water from a kilometre away. People with disabilities (Kelman & Stough, 2015; Sphere Association, 2018; Stough & Kang, 2015), big bodied people (Gray et al., 2022), those with severe mental illness (Eisenman et al., 2009), linguistically isolated populations (Nepal et al., 2012) and children (Ronan et al., 2015), 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 (Sphere Association, 2018, p. 14), “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 verses another one”.

Therefore, the operationalised 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 organise 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. (Mowll, Stewart, et al., 2022)).

### 6.5.3 Emergency planning considerations

#### 6.5.3.1 *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 (1993, 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 (2002), 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 6.3 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” (Civil Defence Emergency Management Act No 33, 2002, Section 17). Such activities could include understanding the potential impacts to communities from emergency events, as carried out by the Wellington Lifelines Group (2019). 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 6.5.2, 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 centres 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 centres and pharmacies should have alternative power supplies installed and available pre-event. The operationalised 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.

#### *6.5.3.2 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 (1985, pp. 376, 377) 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 analysing 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 (Avin & Dembner, 2001; Bartholomew, 2007; Zapata & Kaza, 2015). While this is correct, in the absence of a range of modelled scenarios, the creation of the operationalised 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 6.4.3.2, the hazard chosen for this operationalised 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 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. 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 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 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 analyse 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.

#### 6.5.4 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 organisational 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 organisations, across infrastructure sectors. The creation of an operationalised PELOS framework has been seen by the lead author as a challenging initiative, as it requires organisations to be open about the relative vulnerabilities of their infrastructure. The benefit of having an organisational 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 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 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 organisations 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 6.4.1, this research was carried out as both research and as a WeLG/WREMO project. The collaboration of the various member organisations of WeLG and of WREMO and other key organisations' 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 (2016). 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 organisation 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 (Wellington Lifelines Group, 2012, 2013) and then promoting a programme of works to reduce risk (Wellington Lifelines Group, 2019). The successes of those projects have led to a well-functioning group of organisations 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 (Local Government New Zealand, n.d.). 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 (Wellington Water, n.d.-a). Wellington Water adopted a PELOS (20 litres of water, per person, per day, within 1km of the house, from ‘day 8’) (Wellington Water, 2018b) 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 organisations, 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, recognising that resilience is just one factor of infrastructure management that the owning organisations 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 (Commerce Commission, n.d.). 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 organisational make-up. There are 82 telecommunications and broadcasting network operators in New Zealand, as of April 2022 (Ministry of Business Innovation and Employment Hikina Whakatutuki, n.d.). Both long-distance and local access fibre 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 fibre 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 organisational 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 6.5.1), 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.

### 6.5.5 Flexibility/adaptability of delivery of services

The wording used in the operationalised 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 litres of water, per person, per day, within 1km 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 (2018b)), 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 (1987) and Alexander (2005), 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 “...don't 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 1,200m 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) (Waka Kotahi New Zealand Transport Agency, n.d.-d), roads that have been assessed to be likely available following a major earthquake, for example Fergusson Drive in the Hutt Valley (Wellington Lifelines Group, 2013). 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 operationalised PELOS framework.

## 6.6 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.

### 6.6.1 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 operationalised 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 6.5.2), 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.

### 6.6.2 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 organisations 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 organisation 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 organisation 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.

### 6.6.3 Publicly release framework?

When asked whether it would be acceptable to stakeholders to publicly release the operationalised 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 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, 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.

#### 6.6.4 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 6.3.1). 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.

#### 6.6.5 Was the Action Research methodology appropriate for this work?

Section 6.4.1 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 organisations (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.

#### 6.6.6 Would these PELOS be applicable universally?

Of the PELOS in the preliminary and operationalised 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 litres of water per person per day within 1km of the house”. All other PELOS in the preliminary and operationalised 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, organisational 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.

#### 6.6.7 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 minimise 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 minimised 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 (Wellington Region Emergency Management Office, 2019). 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 6.4.3.2, this approach may not, in any case, change the PELOS identified in the operationalised 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 organisations interviewed, there was potential to gain further opinions from each organisation, 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.

## 6.7 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 operationalised PELOS framework. All of the infrastructure outage studies carried out by WeLG and WREMO (Wellington Lifelines Group, 2012, 2013, 2019) were, in turn, informed by the work of GNS Science in the 'It's Our Fault' project (GNS Science, 2020), 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 (Wellington Lifelines Group, 2019). 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 operationalised PELOS framework. Indeed, the creation of the operationalised framework would not have been possible without them. The vehicle of the Wellington Lifelines Group has been very effective as an organisational 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 operationalised framework against previous work (Wellington Lifelines Group, 2019) 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 1km 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.

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## 7 A new mapping tool to visualise critical infrastructure levels of service following a major earthquake

This section describes how the PELOS, and previously modelled infrastructure outages, were visualised in a mapping tool. This tool demonstrates where PELOS are likely (based on the previous modelling) to be achievable, or not. This required collaboration with Tom Logan and Mitchell Anderson who were, through their own academic study, producing a webtool to visualise infrastructure outages. The collaboration led to the author's input on the requirements to produce the webtool and Tom and Mitch's expertise in developing the mapping tool itself. Specifically, Mitch was the lead author of Section 7.4.2.

The statement of contribution sheet for this paper is in Appendix 1 of this thesis.

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## 7.2 Abstract

How can emergency management teams communicate to potentially impacted communities what a major event causing infrastructure outages might mean for them, and what they can do to prepare? In this paper we describe the process of creating a webtool for end users to visualise infrastructure outages that the Wellington region of New Zealand would face following a rupture of the Wellington fault. This webtool creates insight for three key groups: critical infrastructure owners, communities, and the emergency management sector itself. Critical infrastructure entities can use the tool to understand where they might consider infrastructure upgrades to mitigate gaps of delivery following a fault rupture, and to consider their emergency response plans for delivery in an emergency (leading to their consideration of ‘planning emergency levels of service’). Communities can use the tool to understand what infrastructure outages will mean at the household level in an emergency, including the considerable distances that some community members will have to walk to access services such as food and water and prepare for prolonged outages. Finally, with a greater knowledge of the gaps in delivery and of those community members that might need assistance with food and water collection, the emergency management sector can be better prepared. The methodology for creating the webtool is described, along with the insights that the completed webtool provides for emergency planning.

## 7.3 Introduction

How can emergency management teams communicate to potentially impacted communities what a prolonged infrastructure outage might mean for them, and what they can do to prepare? To support community emergency preparedness, and help infrastructure providers define targets for the delivery of services in an emergency event, the concept of ‘Planning Emergency Level of Service’ (PELOS) was created, as detailed by Mowll, et al. (Mowll, Becker, et al., 2022; Mowll, Stewart, et al., 2022). Many infrastructure providers use the term ‘level of service’ to describe features of infrastructure, through ‘asset condition, performance and other relevant outputs’ (Edwards, 2010). While the term and use of levels of service is a well-understood tool in the management of infrastructure, Mowll, Becker, et al. (2022) found that there are few examples internationally of utilities publicly stating measurable and timebound

levels of service that are specific to emergency response. One of the few examples in Aotearoa New Zealand of a publicly available emergency level of delivery of service is Wellington Water's '20 litres of water per person, per day, within 1 km of dwellings, by day 8' (Wellington Water, 2018b). Such a statement demonstrates Wellington Water's planning intention (hence the term 'Planning Emergency Level of Service' [PELOS]), and their goal for delivery in an emergency. This Level of Service is based on well-researched and authoritative sources (Sphere Association, 2018; World Health Organization, 2003). However, other sectors such as energy, telecommunications and transport are not rich in similarly authoritative sources, and therefore it is harder to establish thoroughly researched PELOS for those sectors (Mowll, Becker, et al., 2022). This paper is presented as a case study of how a tool can be developed as a means for end-users and planners to visualise infrastructure outages from a rupture of the Wellington fault, and to understand the relative likelihoods of PELOS being achieved in such an event. The infrastructure providers will see where, and where not, PELOS are likely to be achievable with existing infrastructure in the region, providing information on where infrastructure upgrades could be considered, or where emergency response plans might need to be developed to deal with outages. For the public, the implications of the outages detailed by the Wellington Lifelines Group (WeLG) from a rupture of the Wellington fault (see below) will provide information on household planning for a major event. For the emergency management sector (including the delivery agencies of critical needs, such as healthcare), a knowledge of existing gaps in the ability of infrastructure providers to deliver services will help to guide where effort should be made in developing response plans. It is recognised that there are other ways of assessing and visualising risk to infrastructure and communities, however the webtool in this paper is presented as a way for the above three sets of stakeholders to visualise the impacts in one tool. This mapping tool could be created for other geographic locations.

The adoption and communication of PELOS can support emergency planning undertaken by critical infrastructure entities (referred to as lifeline utilities in New Zealand) and the emergency management sector, by creating targets for delivery in an emergency. The Wellington Lifelines Group (WeLG) works 'to co-ordinate the physical risk management activities of Wellington utility and transport service providers' (Wellington Lifelines Group, n.d.). The Wellington Region Emergency Management Office's (WREMO's) mission is 'Empowering communities to build the resilience and continuity necessary for the region to be prepared to respond to, and recover from, emergencies' (Wellington Region Emergency Management Office, n.d.-a). WeLG and WREMO have led the creation of PELOS to not only

inform the intentions of critical infrastructure providers in an emergency, but also help infrastructure providers and emergency management inform each other of their response intentions. This inter-organisational work helps the providers to understand interdependency issues, as each critical infrastructure entity will be able to view the modelled levels of service of the other sectors, and therefore understand how those outages will impact their own levels of service. For example, the water provider will understand the power utility's targets for resumption of services, therefore informing the timeframe for restoration of networked power to pump stations.

The power of providing mapped visualisations using web-based GIS mappings are well recognised (Jo et al., 2016; Kerski et al., 2013). This paper describes the process of creation of the webtool and the benefits that it is intended to produce. In essence, this webtool takes the outputs of a WeLG project which calculated the infrastructure outages that would be sustained in a rupture of the Wellington fault (Wellington Lifelines Group, 2019) and presents these in a webmap, comparing the outages against the PELOS developed for the region. While detailed analysis was carried out through that work, it presented infrastructure outages mainly at the suburb-level, which is reflected in the results presented in this webtool. This work provided information on the relative levels of resilience of the infrastructure networks (along with a proposal on how the infrastructure could be made more resilient). While this represented only one hazard scenario (there are many fault locations in the Wellington region (GNS Science, 2020)) and other hazards that could impact the Wellington region (Wellington Region Emergency Management Office, 2019), as detailed by the (Wellington Lifelines Group, 2019), the Wellington fault presents a maximum credible earthquake scenario, and therefore an event that can be planned against (for discussion on this aspect, see Section 7.6.4).

This paper therefore both describes the process of creation of the webtool and the benefits that it is intended to produce. It describes the methodology of the creation of the tool (Section 7.4) before giving an overview of key features of the tool (Section 7.5). A discussion on the features and use of the tool is in Section 7.6. Conclusions are drawn in Section 7.7.

The webtool produced is available at: <https://apps.uintel.co.nz/wremo>

## 7.4 Methodology

### 7.4.1 Research context

The mapping tool presented enables community members, critical infrastructure entities and members of the emergency management sector to visualise how infrastructure outages from a rupture of the Wellington fault would impact them. This visualisation can be seen ‘for [the] public’, showing walking distances to water, food and community hubs, and ‘for [the] planners’, showing numbers of people impacted and areas that have either good, or poor, service coverage.

The work presented in this paper is a component of a broader study which firstly proposed a PELOS framework for a large earthquake on the Wellington fault (Mowll et al., 20xx) and then operationalised this framework (Mowll et al., 2022). The overall PELOS project was carried out using Action Research methodology, where a researcher who works within an organisation researches an aspect of the work (McNiff, 2013). This methodology was utilised as the lead author of this paper is the Project Manager of WeLG and the Lifeline Utilities Co-ordinator with WREMO. Such a process is not unique in New Zealand, as the lifelines groups around the country participate in collaborative projects (for example, (Wilson et al., 2014)).

For the research/project methodology, the overall process for the broader study is described in (Mowll et al., 2023a), however the key steps for creating the mapping tool are, as shown in Figure 7.

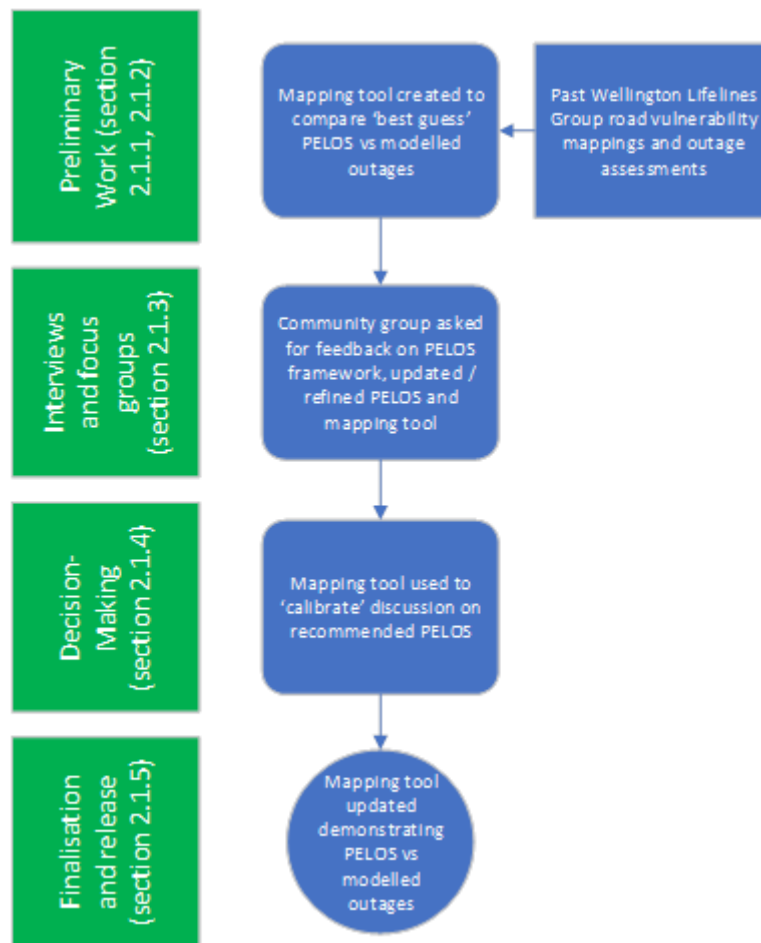


Figure 7: PELOS mapping tool creation process. Part-reproduced from Mowll et al. (2023a)

#### 7.4.1.1 Steps taken in developing the webtool

This section broadly follows the steps taken in Figure 7, but gives greater detail on the steps shown in the figure. The source of the data used in the webtool is described in 7.4.2.

#### 7.4.1.2 Mapping tool created to compare 'best guess' PELOS vs modelled outages

To test the usefulness and viability of comparing PELOS to modelled outages, a prototype mapping tool was developed. This prototype was relatively simple in its format and functionality but demonstrated that a comparison between the PELOS and the outage times identified from the above reports could be mapped. The prototype was discussed with emergency managers to ensure that proceeding with further work on the tool was worthwhile

and some improvements suggested by emergency management staff at WREMO were incorporated at this stage, regarding features of the webtool including how infrastructure in parts of the region then not covered by the webtool were shown (for example, emergency water provision to the Wairarapa in the east of the region. Having established that there was an appetite to develop the tool further, the following steps were then taken.

#### *7.4.1.3 Community group asked for feedback on PELOS framework, updated/refined PELOS and prototype mapping tool*

To evaluate the usefulness of PELOS and the prototype mapping tool, two additional workshops were held with community members. The first workshop focussed on the usefulness of the concept of PELOS (Mowll et al., 2023a). A second community workshop then asked participants for feedback on the usefulness and functionality of the prototype mapping tool. The question sheet used for that workshop is included as supplementary information to this paper [included in Appendix 10]. In summary, the community workshop members ran through a set of tasks used to establish the user-friendliness of the tool, and how easy it was to extract relevant information from it. At the time of the second workshop, the mapping tool opened on the ‘for planners’ section, with a separate button available for inserting the tool-user’s address. Therefore, this workshop covered both the ‘for public’ and ‘for planners’ sections.

The output of the workshop was a set of suggestions for improvements, considering both the usability of the tool and its visual appearance. The collated feedback from the community workshop is also included in the supplementary information [included in Appendix 10]. As can be seen from that output, some of the questions posed to the workshop participants required free text responses (e.g. ‘during days 8-14 after a disruption, is the New World [supermarket] in Karori expected to be open or closed?’). These tested whether the webtool was easy to use by participants to ascertain information. In the case of that question, four participants responded correctly and two incorrectly. This indicated that the function of the webtool was not fully intuitive to use, leading to the development of the ‘tutorial’ function in the webtool. Additionally, participants were asked to provide ratings to some questions, for example, ‘As a resident, does the site provide adequate information around how to prepare for a disaster?’, with responses requested from ‘definitely not’ to ‘definitely’ (in this case, there was a spread of responses from 3/5 to 5/5). This again led to various site improvements including, links from

the webtool to the WREMO preparedness website (Wellington Region Emergency Management Office, n.d.-f).

From this process, key updates from community feedback included the following:

- After the landing page, the website was split into two access points ‘for public’ and ‘for planners’, so that the public are directed to a simplified output relevant to their address and planners can carry out greater analysis on resilience and emergency management issues.
- Various colours and visibilities of text on the website were updated to ensure that key aspects of the website were highlighted.
- The tutorial button was introduced into the ‘for planners’ page, to enable users to get help on using the website.
- An autocomplete was included, so that when users are inserting an address, it makes confirmation of the address easier.
- Updating the wording used on the ‘for public’ section of the webtool, including changing some of the language to be more suitable for laypersons, such as renaming ‘wastewater (wees and poos)’ to ‘toilets’.

#### *7.4.1.4 Mapping tool used to ‘calibrate’ discussion on recommended PELOS*

The prototype mapping tool was then updated using the ‘operationalised’ PELOS framework, which is presented by Mowll et al (REFERENCE – this reference to be updated when there is a stable reference). The changes between the PELOS stated in the preliminary framework and the operationalised framework were not different in terms of how they would be presented in the mappings, so no significant changes on the PELOS used in the preliminary and operationalised framework were required. Once this updated mapping was complete, it was used to engage key decision makers on the finalisation of the PELOS stated in the operationalised framework. This was carried out during a workshop held with the key stakeholders, mainly critical infrastructure entities and emergency management bodies of the Wellington region (for further details of this process, see Mowll et al. (2023a) for details on the methods, analysis and results of this workshop).

#### *7.4.1.5 Mapping tool updated demonstrating PELOS vs modelled outages*

In addition to these updates from the community workshop, WREMO staff members from the Community Resilience team, who work with Wellington region communities to raise preparedness for emergencies, provided feedback to ensure that the mapping tool used language and messaging consistent with the language used by WREMO on its public-facing products. Further updates to the webtool were also made at this time, based on the latest information available, such as the locations of supermarkets (see section 7.4.2.1).

### 7.4.2 Underlying data used in the tool

When considering what infrastructure services communities need in an emergency, it is necessary to consider both the provision of critical infrastructure at the property level as well as the accessibility of operational amenities from dwellings (Buckle et al., 2000; Logan & Guikema, 2020). To assess this, Python, Open Source Routing Machine, and various open-source datasets were utilised. This section discusses the required data inputs, processing methods, and development required to formulate this information and house it within a webtool.

#### *7.4.2.1 WeLG road vulnerability and infrastructure outage assessments*

In order to understand the scale of potential durations of infrastructure outages for the region, it was necessary to have some base-line information as a starting point for discussions on both PELOS and for creating a mapping tool. Information gathered from previous Wellington Lifelines Group reports were used as the base infrastructure outage information for the mapping tool. The road vulnerability mapping shown by the Wellington Lifelines Group (2012) (in Appendix 2 of that report) and the grid matrix used to outline road outage times by the Wellington Lifelines Group (2019) (in Figure 5.2 of that report) were used as the sets of base information for understanding road outage durations. For the webtool, this is used as a basis for demonstrating when supermarkets can be re-stocked. Both of those reports are based on the hazard of a rupture of the Wellington fault, producing a large earthquake impacting the region,

which is why this mapping tool is based on that hazard. The outages of other utilities (e.g. power (electricity), water, telecommunications) used in the webmap were taken directly from the Wellington Lifelines Group (2019) report.

#### *7.4.2.2 Population and facility data inputs*

Community members and emergency managers, or ‘end users’, are the crux of emergency management planning. Using 2018 census data from (Stats NZ, n.d.; University of Otago, 2018) for the Wellington Region, spatially explicit information on various socio-demographic groups (e.g., people with mobility-impairments, or classed as vulnerable or socially deprived) was used as an input to the webtool. In New Zealand, this spatially explicit information is provided at the statistical area 1 (SA1) level and statistical area 2 (SA2) level. SA1 is the smallest census spatial area produced by Stats NZ and includes, on average, 100-300 people. It includes information such as population, ethnicity, social deprivation indices, and household income. This is important to enable planners to identify areas that may require more support to prepare or recover following a prolonged infrastructure outage.






SA1 level information gives useful results when assessing a regional or suburb-scale picture but lacks granularity when compared with individual household information. Building outlines (Land Information New Zealand, 2023) were used as an input to the webtool to amend this. This information enables property specific results to be reported and communicated. This is discussed further in section 7.5.

The Transportation Network is a required input to understand if users and goods can be transported between locations. Ultimately, this indicates whether critical infrastructure can be accessed for repair and maintenance, if supplies can be made available at specific locations for the function of certain amenities, and the ease with which users can reach locations of interest. Roding information for this analysis was taken from two sources, (1) OpenStreetMap for routing (OpenStreetMap Contributors, 2017), and (2) the road outages from the Wellington Lifelines Group (2019) report.

The Amenity (Destination) categories refer to locations that provide a vital function, post-event. Determining the types of amenities to include should be based on the needs and values of the community and, in practice, should be selected based on engagement with local

governments and communities (Robertson & Simonsen, 2013). The amenities used within this study are summarised in Table 15.

Table 15: Details of the amenity types used within this study and their source.

	Amenity	Description	Source
	Health Service	Medical centres and hospitals.	Logan et al. (2022)
	Community Emergency Hub	A Community Emergency Hub is a place where neighbours can go to help each other in a major emergency.	Wellington Region Emergency Management Office (n.d.-b)
	Water Distribution Point (or 'Collection Points')	Locations for the community to collect water from, in an emergency.	Wellington Water (n.d.-d)
	Supermarket	Supermarkets based on supermarket company information as they existed in 2020.	Land Information New Zealand (2023); (Logan et al., 2022)
	Fuel Station	Fuel station, also known as a filling station, petrol station, gas station and petrol garage.	OpenStreetMap Contributors (2017)

The Infrastructure categories include power (electricity), telecommunications (phone and internet service), FM/AM radio & TV, and toilets (on the 'for public' section or 'wastewater (wees and poos) on the 'for planners' section). These infrastructure types are considered at a sub-regional level and are mapped based on infrastructure coverage. The webtool does not use or require the location of the nodes and edges within each network, but rather the area that they service, as defined in the Wellington Lifelines Group (2019) report.

#### 7.4.2.3 Infrastructure functionality data inputs

To provide accurate and informative information we utilised expert elicitation to understand how each network will react to the potential event and therefore, what level of service it may provide over each timeframe. For the amenity categories, this requires knowing whether the infrastructure supplying any given amenity is functional. For example, for a supermarket to

operate, it requires power and water supplies and, an operating internet connection to process debit card transactions (acknowledging that some supermarkets can ‘cache’ transactions during an outage, until the internet connection is restored). Each of these functions was taken from the Wellington Lifelines Group (2019) report. Expert elicitation was used to interpret where there were gaps in the information available in the report, for example, where a supermarket was located close to, but not within, the area being assessed.

The method for assessing this functionality, described in section 7.4.1.1, determines the state of all amenities and all infrastructure service areas for each timeframe. These classifications are described in Table 16. The functionality of critical infrastructure matches the descriptions in the WeLG report (Wellington Lifelines Group, 2019).

*Table 16: Functionality classifications of amenities and critical infrastructure*

	<b>Amenity Classification</b>		<b>Critical Infrastructure Classification</b>
	Open		Functional (80%+)
	Open – stock dependent		Partially Functional
	Closed		Non-Functional or Unknown

These results are analysed and mapped over timeframes modified from (Mowll et al., 2023b). We define the day the hazard event occurs as day 0, before mapping the varying levels of service for the timeframes of 0-7 days, 8-14 days, 15-30 days, 31-90 days, and 90+ days. This modification includes the addition of the ‘days 8-14’ timeframe, a timeframe that is not included in Mowll et al. (2023b). This amendment was made due to the availability of data for the mapping and was seen as a useful addition by the webtool developers and WREMO to add further detail on the restoration of services.

#### *7.4.2.4 Access to facilities data inputs*

To demonstrate on the webtool access between inputted addresses and operational amenities the webtool uses street network routing from every building in the region using methods described in (Anderson et al., 2022; Logan et al., 2019). For each timeframe after the hazard

event, the webtool uses inputted addresses as origins, and pre-determined operational amenities as destinations, and uses a modified transport network that allows pedestrian access on otherwise non-operational roads. Using Python, SQL, and Open-Source Routing Machine, the origin and destination pairs were prepared and analysed. This analysis returns a matrix of distances and durations for each origin and destination pair. The shortest distance is kept and reported in the webtool output.

Access is visualised at a regional level by aggregating information at a SA1 level by the average distance each SA1 would have to travel to the selected amenity. This is grouped into six bins as demonstrated in Table 17.

Table 17: Walking distance categories for access to amenities

	<b>Walking Distance</b>	
	<b>Supermarkets, Health Care, Community Emergency Hubs, and Fuel Stations</b>	<b>Water Distribution Points</b>
	0-2 km	0-1 km
	2-4 km	1-2 km
	4-6 km	2-3 km
	6-8 km	3-4 km
	8+ km	4+ km
	Isolated	Isolated

The bins for grouping and visualising access can be changed depending on the population and amenity. The choice of 2 km and 1 km as a walking distance to the respective amenities is detailed by Mowll et al. (2023b). The colours shown in the webtool for access to supermarkets, health care, community emergency hubs, and fuel stations commence with the 0-2 km distance and rise in 2 km steps. This shows the distance that residents would have to travel from their home to the nearest operational facility following an event. This process was mirrored in the access to water category, noting that the PELOS for water is 1km to dwelling (Mowll et al., 2023b), with the steps shown for water in 1 km steps. (As described in (Mowll et al., 2023b), the 1km distance for water collection matches the World Health Organisation’s basic access to water standard, and the 2km distance to supermarket is the distance based on the available literature and expert opinion.) The advantage, for planners, of being able to view those different

distances is that emergency planners will be able to see how many community members may require assistance in an emergency to access water and food.

#### *7.4.2.5 Household level impacts data inputs*

To provide household-level information for PELOS at each timeframe post event within the webtool, each building was reverse geocoded. This enables users of the tool to enter their address to the webtool and receive instant results on potential impacts. Reverse geocoding is a process that assigns an address to a particular location, such as a building, based on its coordinates. By reverse geocoding each building outline to its respective address, it is possible to display modelled information at the property level, which provides more granular data than what is available at the census level. In this way, it is possible to report and communicate property-specific results for infrastructure services, which is a clear advantage in the use of this webtool for enabling community level preparedness.

For visualisation purposes, the web-tool shows results aggregated from the household level to the SA1 level. This enables viewers to better understand the variation in level of service around the region.

#### *7.4.2.6 Coding the web-tool*

The development of the web-tool to visualise the modelled results involved the use of standard front-end development programming languages and tools, including JavaScript, Leaflet, HTML, and CSS. These languages and packages were chosen for their ability to create dynamic and interactive web functions, as well as their ease of use and compatibility with a wide range of web browsers. One of the main challenges in developing the web-tool was how to effectively communicate the vast amount of information stored in the database to users in a way that was clear, concise, and easy to understand. To achieve this, the iterative approach that utilised stakeholder and user feedback as detailed in section 7.4.1.3 was followed.

## 7.5 The Tool: An Interactive Dashboard

This tool aims to provide a comprehensive view of PELOS, both regionally and at an individual property level. The webtool was structured with three key areas: the landing page, a section ‘for public’ and a section ‘for planners’. While all three sections are intended to be available to all users, each serves a distinct purpose.

### 7.5.1 Landing page

The landing page provides the context for the webtool, including information on the base data used in the mappings. Ultimately, this page is designed to introduce the webtool while also providing additional resources to either encourage emergency preparedness or better understand the information presented in the webtool. The ‘for public’ and ‘for planners’ sections are linked from this landing page.

### 7.5.2 ‘For planners’ section

The information provided in the ‘for planners’ section shows numbers of residents receiving different levels of service to both amenities and networked infrastructure sectors. This includes an overview of the region and sub-regions over time, as well as a graphical representation of various demographic types. For first-time users of the webpage, a tutorial set of instructions appear on first-use of the site (and can be re-seen via the ‘Tutorial’ button to the right of the page). While WREMO staff may carry out walk-throughs of the site with community groups, the tutorial part of the webpage was tested (see Section 7.4.1) and then considered by WREMO and the authors to be sufficient to enable users to engage successfully with the tool). These functionalities in the ‘for planners’ section can be seen in Figure 8.

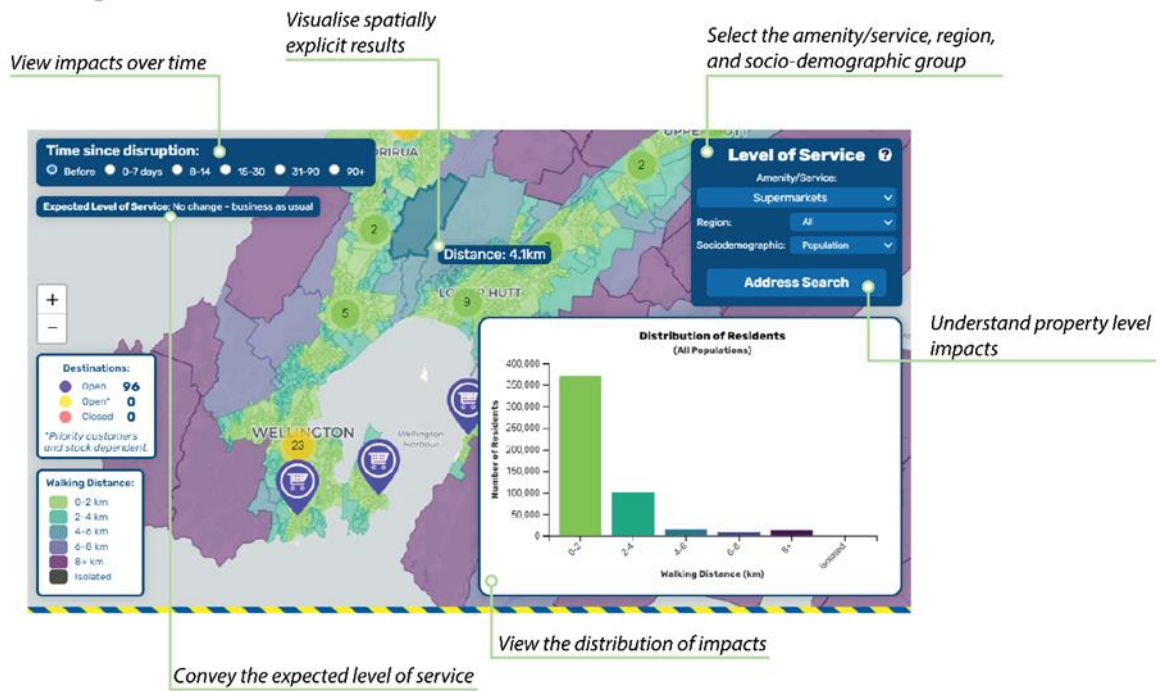


Figure 8: Functionalities of the 'for planners' site section

### 7.5.2.1 Networked infrastructure sectors

As an example of the output of the webtool, we consider the provision of critical lifeline services to residents over the first 90 days post-event. Figure 9 shows how the level of service for electricity varies across the region over different timeframes. This is, essentially, a visual representation of the outage mappings produced by the Wellington Lifelines Group (2019). It allows for an easy comparison against the PELOS outlined in (Mowll et al., 2023b).

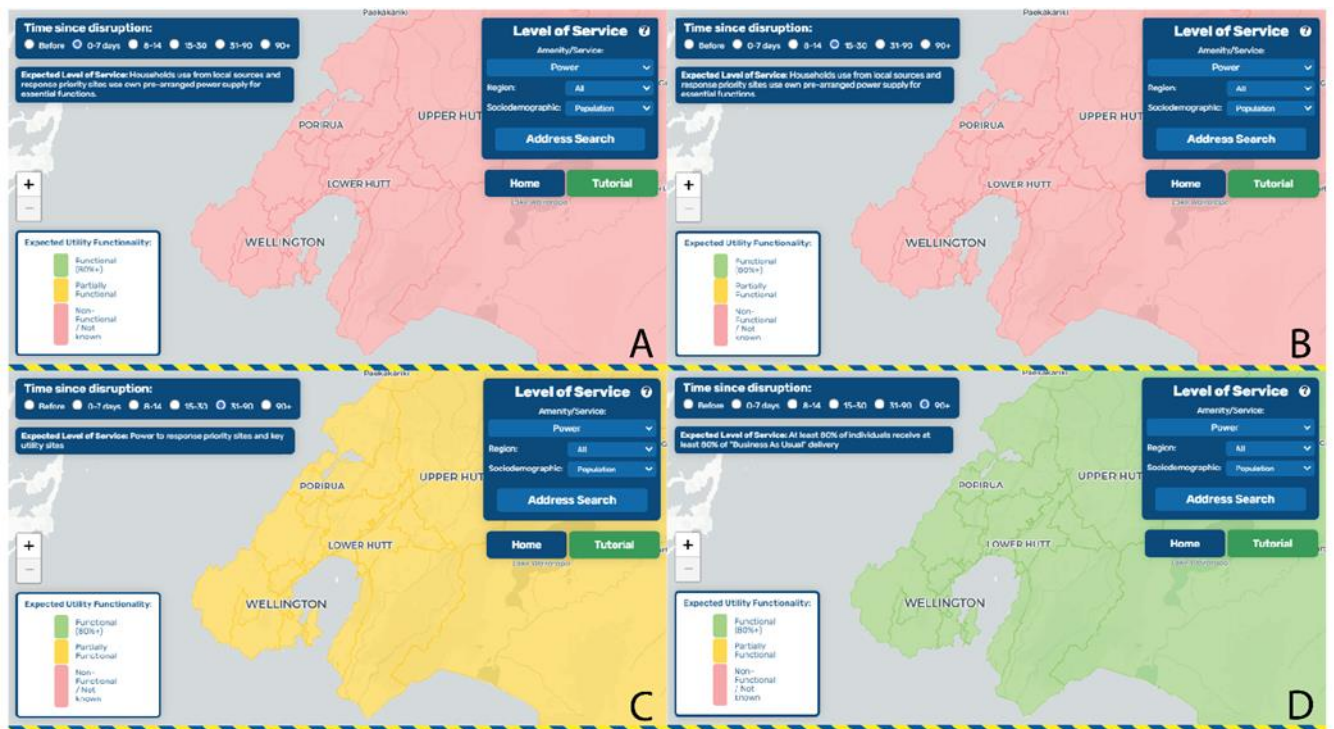


Figure 9: Electricity level of service over time. Region-wide view demonstrating the ability for facilities and homes to access power. A) 0-7 Days. B) 8-30 Days. C) 31-90 Days. D) 90+ Days. Red describes that the service is non-functional; Orange/Yellow is partial functionality; Green is >80% functionality.

### 7.5.2.2 Accessing key amenities

The webtool also enables residents to determine their access to key amenities in terms of walking time.

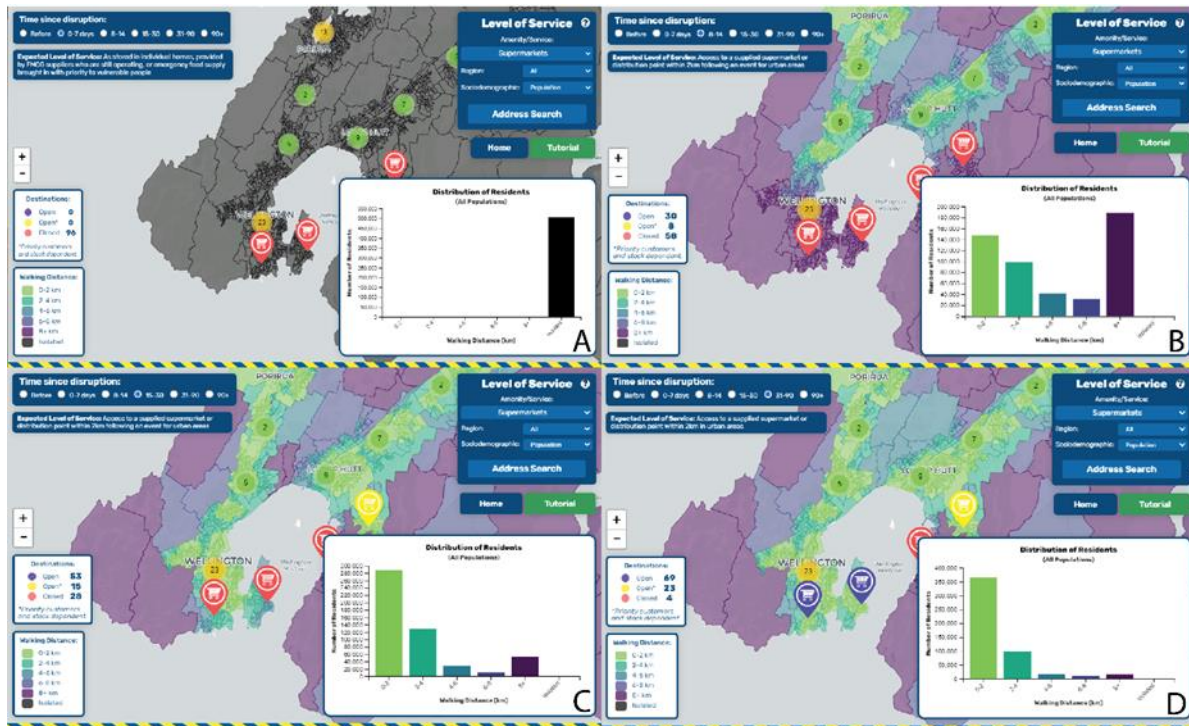


Figure 10: Accessibility to food sources over time. shows how access to supermarkets changes over four time periods post-event: 0-7 days, 7-14 days, 15-30 days, and 31-90 days. Figure 4(a) shows the total loss of access to supermarkets (due to loss of road access between distribution centre and the supermarket, meaning that restocking is not possible by road), demonstrating why residents throughout the region should store enough food supplies for their household for the first seven days post event (as highlighted in WREMO's household preparedness resources (Wellington Region Emergency Management Office, n.d.-f)).

Figure 10 depicts how access is slowly returned to residents, where some supermarkets reopen, as shown by the changing colours over the geographical area (see Table 17 for the colours used). However, there are several areas that will remain very far from their nearest open supermarket. This shows walking distances in those areas of >8 km. During the timeframes of 8-90 days, supermarkets shown with a yellow icon, seen within the Hutt Valley, are only operational based on the emergency response plans to re-supply stocks to those areas, which would depend on an emergency supply chain, as the main roads serving the Hutt Valley are expected to be vulnerable to outages (Wellington Lifelines Group, 2019). Again, this highlights the need for both community members and emergency planners to plan for lengthy outages of road access.

### 7.5.3 For public

The ‘for public’ area is a simplified output of the outages relevant to individual addresses. In this section, a user can input a street address, and this will provide information about what levels of service they can expect and should prepare for following a prolonged event. The intention is to help householders understand the potential impacts of, and prepare for, potential emergency events. An example output is shown in Figure 11.

The walking distances to access food, water and a Community Emergency Hub following an event can be modified by updating the number of trips they expect they will need per week to visit each of those services and shows the total walking distance in kilometres that they would need to travel. Further, a toggle allows the webtool user to switch from distances walked per week to number of minutes taken to walk to the various services per week. The networked infrastructure outages for the address are also shown immediately below the walking distances table (as taken directly from the ‘for planners’ section of the webtool).

Finally, a ‘print results’ button allows the webtool user to print the results for their selected street address, allowing householders to compare their predicted levels of service alongside key emergency preparedness messaging provided by WREMO, which is included in the print version of the outputs.

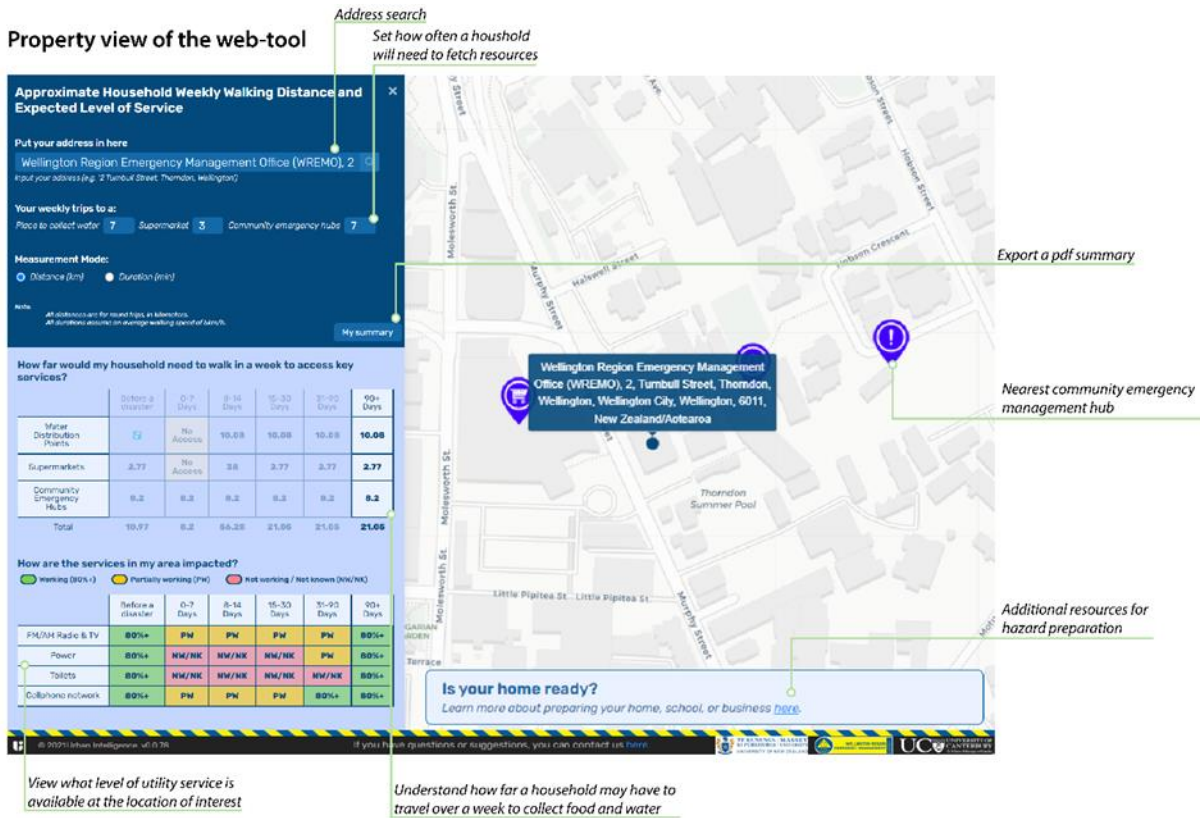


Figure 11: Option for residents to explore what their levels of service are over time based on their address

## 7.6 Discussion

### 7.6.1 Functionality of the webtool

So, how can emergency management teams communicate to the potentially impacted communities what a rupture of the Wellington fault might mean for them, and what they can do to prepare? The objectives of the webtool, as highlighted in Section 1, were to provide a visual representation of PELOS, and for critical infrastructure providers, community members and the emergency management sector to be able to visualise planning and response/recovery timeframes.

For the demonstration of water and food access PELOS, the webtool provides two key features. Firstly, in the ‘for planners’ map function, the colours provided on the map for 0-2 km distance for distance to an open supermarket and 0-1 km distance to a water distribution point provide a quick visualisation. This helps the water and emergency management sector understand the

areas that are outside the PELOS (1 km and 2 km respectively), and therefore the areas that communities may require additional support to access services, post-event. Further, the bar chart provided in the bottom right corner of the ‘for planners’ section gives a quick visual indication of the numbers of community members that are within each access zone. This is further enhanced by the breakdown in the top right corner of the ‘for planners’ section of the webtool for suburb-level areas and for those community members that either have difficulty walking or are socially deprived. These features satisfy the original intention of demonstrating PELOS against a model of outages (Wellington Lifelines Group, 2019), and indeed deliver the additional benefits of demonstrating the impacts on potentially further impacted communities.

The ‘for public’ section of the webtool has the potential to give good insights for households to understand the scale and features of immediate post-earthquake events. A key feature of the webtool is that the information is not just delivered without context but is shown alongside WREMO messaging for preparedness actions the community can take. The intention here is to inform community members of modelled outages, but to then help people proactively prepare for ‘worst case scenario’ emergencies.

Comparing, therefore, against the original webtool objectives, from the perspective of providing a technological tool, the authors believe that those objectives have been satisfied. The usefulness of the tool to the public will be better understood on its release.

Comparisons to other tools that are available for other contexts is difficult, as this is a novel tool that focusses on PELOS (we are not aware of other regions having developed PELOS in other regions), but there are other dashboards. The closest example is the paper on access to services by Logan and Guikema (2020) which outlines how a hurricane impacted access to Wilmington in the USA in 2018 (dashboard available at <https://research.uintel.co.nz/resilience-florence/> ), including how access changed over time. Otherwise, a range of community emergency and climate preparedness tools are available from the City of Calgary (2024) and the University of Central Florida (n.d.) however these do not have computational analytics behind them, as were developed for the WeLG/WREMO webtool.

### 7.6.2 Process/approach overview

Was the methodology taken appropriate to achieve the above objectives? The methodology taken for the creation of a PELOS framework and this webtool, as demonstrated in Section 2, is iterative in nature, in that four separate versions of the webpage were required: a prototype to demonstrate that the webtool could be created, another version for the critical infrastructure providers to visualise modelled outages, an updated version used for feedback at a community workshop and the final version (as presented in this paper). While this required multiple steps to create the final version, it has created a more polished product that satisfies the original objectives of the webtool. Without such an iterative process it is unlikely that such a relatively polished product could have been created.

### 7.6.3 Key insights from the webtool

As demonstrated, the mapping functionally demonstrates where PELOS have been compared to modelled infrastructure outages. One of the key learnings gathered is the long walking distances required for many households. One example, using the suggested ‘generic’ address given in the ‘for public’ section of the webtool – 2 Turnbull Street, Thorndon, is that over days ‘8 to 14’ a person making 14 trips to collect water (assuming two people reside at the address and just one person is collecting the water), three trips to an open supermarket and three trips to a community emergency hub per week would have to walk 61.7 km that week (an average of 8.8 km per day), of which 10 km would be transporting 20 kg of water and 19 km would be carrying shopping. This is in addition to any trips to medical centres or other facilities. This is a substantial amount of walking, even for the fit and healthy. As highlighted in Section 3, those that are less mobile (the very young, old or those having difficulty walking) will not be able to access water and food themselves. Some of these people may be provided for by their carers (e.g. the parents of small children), but this creates an additional burden of collection on those carers. Some community members may not have carers to provide for such needs. This highlights the need for working pre-event to identify where gaps may exist for the delivery of services to the community, and where work can be carried out to bridge those gaps. By days ‘15-30’, the distances drop to 26.4 km overall, but the issues of collection persist. For a community member seeing these figures, it is hoped that this will provide a prompt to store

water and food at home to minimise walking distances post-event. There may be many reasons why community members have not stored water or food at home (Blake et al., 2017; Meyer-Emerick, 2016), but this webtool does provide a basis for the planners to understand where there might be gaps for some community members, and therefore needs, to address.

#### 7.6.4 Limitations

There are presently some limitations of the inputs to the model. Firstly, the modelled infrastructure outages, as taken as an input to the webtool from the Wellington Lifelines Group (2019) report, are relatively simplistic, showing only 'on' or 'off'. That report details that power supply should be viable '3 to 6 months' following a rupture of the Wellington fault for a large part of the Wellington region. This does not allow for some facilities (for example the hospital) having their own generators, as detailed in the relevant PELOS, with the webtool only showing power is out for an area or the potential for degraded supply being available for parts of the response in some locations. This is not an aspect that can be immediately addressed through this webtool, however the concept of PELOS (which is referenced in the landing page of the webtool) does provide some of that context and texture and can be accessed by webmap users that require further information.

Methodologically, a key limitation of this research has been the relatively limited engagement with end-users, with a single community workshop conducted on the use of the webtool. While the workshop was valuable in demonstrating the ease (or otherwise) of the use of the tool, it provided a relatively limited set of perspectives. Greater engagement with other community members or groups would help in understanding how those, for example, for whom English is not their first language, or with accessibility issues would engage with the webtool would enhance it further.

The walking durations do not consider elevations or unknown access limitations post-event. Many of the suburbs in the Wellington region are relatively hilly, meaning that the transport of water or supermarket shopping up hills will likely take longer, as the current travel times assume a 5 km/hr walking speed. The adjustment of walking times to allow for hills would improve the tool.

An additional limitation of this study is that the population data used is based on the 2018 census, which is now five years old. This data may not accurately reflect current population dynamics, potentially limiting the generalizability and applicability of the results. The source data for the population can, however, be updated with each census, allowing for the most recent dataset to be used.

Additionally, it is impossible to predict with certainty which services will, or won't be, available post-event in an emergency, particularly a major earthquake. For example, supermarkets and medical centres may not be operating post-event for a variety of reasons, such as loss of infrastructure services or lack of staff. Further, water collection points may be moved to suit specific circumstances post-event, landslips may unexpectedly block some roads and nearby building damage might limit access through some routes. Thus, the 'disclaimer' information provided on the landing page is important, to demonstrate that the information shown is only at the level of certainty that such a model can provide. This 'disclaimer' reads:

"No infrastructure service can ever be guaranteed, especially following a major event such as a rupture of the Wellington fault. Please note that in an actual event the services available will depend on exactly what damage has happened and what staff are available to respond."

A further limitation is that only one hazard scenario has currently been used to demonstrate the achievability of PELOS against modelled outages (a rupture of the Wellington fault). A similar presentation of outages and walking distances etc. may be possible if future modelling is carried out on outages from tsunami impacts or other hazard events/scenarios. At present, the rupture of the Wellington fault has been taken as a relatively unlikely, but representative, 'worst case scenario' earthquake event (Wellington Lifelines Group, 2019), and is therefore the only hazard event represented on the webtool.

Another limitation is that one of the caveats given in the PELOS framework is that 'end user experience may vary'. This is an acknowledgement that services cannot be guaranteed to all locations to a particular level of service, post-event. For example, there may be long waits to collect water at distribution points, or to collect food from the supermarket, where, additionally, only limited food options may be available. Equally, as these are a set of planning emergency levels of service, with the emphasis on 'planning', this webtool should primarily be considered as a preparedness tool. Communicating this difference is a key factor that was considered by WREMO and the WeLG and Wairarapa Engineering Lifelines Association members before agreeing to publicly release this mapping tool. Balancing the usefulness of the information

shown against the potential for misuse of the information post-event (in the case that delivery did not match the modelling) was a key factor in this decision.

Finally, the webtool is based on a single hazard scenario – a rupture of the Wellington fault. Future versions could potentially include other scenarios such as tsunami or flooding impacts.

From the above, future potential enhancements include the depiction of other hazard scenarios, for example from climate change impacts, and the incorporation of other changes based on the public use of the site and therefore feedback gathered from the Community Resilience team at WREMO. There is currently no formal process for gathering feedback and providing an assessment on this webtool, as WREMO will gauge the level of interest from the public before considering whether further development justifies further development resource.

#### 7.6.5 What have we learnt from this process?

The webtool has created a visualisation of the impacts on infrastructure and households of a rupture of the Wellington fault in a way that should be understandable to community members. The Action Research methodology used in this research allowed the lead author to carry out research within his organisation, a factor that allowed freedom to explore the development, and potential use, of the webtool. The steps taken in the methodology for this project (as outlined in Section 2.2) allowed for an iterative process to develop the webtool.

The key issues highlighted through the overall methodology are that, it has been functionally possible to compare, on a webtool, modelled outages (Wellington Lifelines Group, 2019) against a set of PELOS (Mowll et al., 2023b). Secondly, producing a webtool such as the one presented better informs following emergency planning steps for both the emergency management professionals and the community. This presents opportunities for communicating Wellington fault rupture impacts to three different groups: infrastructure managers, the emergency management sector, and the community. There is the potential for wide adoption of this type of approach internationally.

One of the key values of a tool such as this is the stress testing of the underlying ideas due to the accessibility of the information. Assumptions and, in some cases, limited theoretical bases for them, become more apparent. Wider adoption and uptake would drive additional investigation into some of these limitations for disaster resilience planning worldwide.

Additionally, viewing the webtool allows stakeholders and community members understand the implications of outages. For example, how will emergency services drive (or not) to responses? ‘How long will power outages be where I live?’ The webtool allows such thoughts, leading to conversations around the relative resilience of infrastructure. It is hoped that this will lead to conversations on how resilience is valued, and how all parties can prepare for emergencies whilst the current infrastructure is in place.

#### 7.6.6 Applicability to other regions

The key aspects of the production of the webmap that aided a good outcome were to have clear platform objectives and have early engagement with the users. As detailed in Section 1, the objective of the tool was to demonstrate where PELOS could, and could not, be achieved in a way that could be understood by the public. For engagement with the users, WREMO staff were involved in the development process from an early stage and engagement with end users was carried out to ensure that the public would be able to interface with the tool.

While the mapping of modelled outages through a similar webtool could be created in any region that has access to modelled outages, this mapping tool could only be used in a region that has also defined its own PELOS, or chooses to adopt similar ones to those identified for the Wellington region (Mowll et al., 2023b).

### 7.7 Conclusion

A mapping tool has been developed to visualise PELOS. It serves as a valuable resource for planners and emergency managers alike, allowing them to better understand the unique requirements of different communities. Additionally, members of the public can access this tool to obtain specific information about how their community may be impacted in the event of an emergency, allowing them to take proactive measures to protect their homes and businesses. In summary, this tool plays a critical role in promoting community preparedness by providing essential information to both planners and members of the public. Through its comprehensive approach to PELOS, it is intended to empower individuals and communities to take proactive steps to ensure their safety and security in the face of future emergencies. The tool enables

users to examine the modelled outages after a potential Wellington fault rupture over five different time periods for five different amenities and four different networked infrastructure sectors. These include access to food, hospitals, water, emergency management hubs, and fuel/LPG; and the functionality of electricity, telecommunications, radio broadcast, and wastewater services.

While there are limitations on the usefulness of the tool, including that it currently has focussed on one hazard scenario, and that it cannot consider the variabilities of end-user experience, we propose that this is a useful tool for communicating the general outcomes on infrastructure outages that may be seen in following a major earthquake impacting the Wellington region. Ultimately, with the insights that the webtool provides, alongside the concept of ‘planning emergency levels of service’ households, communities, infrastructure providers, the emergency management sector, and the Wellington region, can plan for emergencies better, and therefore become more resilient. As the data and outputs used in the tool are drawn from open-source repositories and methods, different regions, have the option to create a similar mapping tool using their own modelled infrastructure outages and PELOS, or using the PELOS created in the Wellington region.

The methodology used, including the collaboration between academic researchers, the critical infrastructure entities and the emergency management sector has been proven to deliver a webtool that will help emergency preparedness communication. The implication is that this tool, or similar can be developed and used in other contexts and for other hazards. As detailed in Section 7.6.4, there are various improvements that can, in time, be made to the webtool.

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## 8 Discussion

### 8.1 Context

The Wellington region is vulnerable to natural hazard events. A rupture of the Wellington Fault is a relatively low-probability event, with a 640-year return period (GNS Science, 2020), but, even though other earthquake faults are known (see Figure 1), the Wellington Fault has been used in emergency management and by critical infrastructure entities as a representative large-scale earthquake, for emergency management and risk mitigation studies (Wellington Lifelines Group, 2013, 2019). While the impacts of fault ruptures are now well known, the goals of the critical infrastructure providers for response and recovery have been less well understood, whether the event be an earthquake, a storm, a tsunami or any major event. This research for this thesis was carried out with critical infrastructure entities and emergency management practitioners to create a framework of goals for response and recovery – ‘planning emergency levels of service’. Such goals may go some way to providing the linkage of understanding between the goals of the critical infrastructure entities and the needs of the community in an emergency event. With knowledge of what the infrastructure entity intends to provide, the community can prepare for response with a better knowledge of what services are intended to be provided to them.

As a key step, using the PELOS as a basis, a gap analysis was then conducted, through the creation of the mapping tool, to visualise, at suburb level, walking distances to food and water supplies in an emergency, where the levels of service could, and could not, be achieved. This should help critical infrastructure entities understand key foci of their emergency response plans and allows them to understand where future network upgrades may provide greater resilience. Similarly, emergency managers can see where there are likely to be shortfalls in services to the community, therefore understanding where emergency response plans may be required to be developed to address the shortfalls. Finally, the community members themselves, using the mapping, can envisage the impact that a major earthquake will have on the services delivered to them, allowing them to plan for their own responses to an emergency.

While a literature review highlighted that internationally similar work had been carried out in the West Coast of the USA on articulating the goals of critical infrastructure entities in response and recovery (Oregon Seismic Safety Policy Advisory Commission, 2013; Poland, 2008;

Washington State Seismic Safety Committee Emergency Management Council, 2012), what this meant for the impacted communities was investigated less. With few examples of how the goals in a response and recovery of critical infrastructure entities could be articulated, this research, as part of a project being carried out for the Wellington Lifelines Group and the Wellington Region Emergency Management Office, has pioneered a new approach to articulating such goals and impacts.

## 8.2 Methodology and methods

The qualitative action research methodology was chosen for this study due to its applicability to situations in which practitioners investigate aspects of their work. McNiff (2013) describes it as ‘on the job’ research, and that is how this research was carried out, by me, delving deeply into an aspect of a project that was being carried out for the Wellington Lifelines Group and the Wellington Regional Emergency Management Office - both organisations that the author holds roles with. The action research methodology allowed for in-depth discussions to be carried out with, and data to be gathered from key stakeholders – the critical infrastructure providers and emergency management professionals of the Wellington region – on a working issue. This research addressed a ‘gap’ in knowledge about how infrastructure outages could be understood and planned for. As such, while there was some literature that provided examples of frameworks intended to perform a similar function, from the West Coast of the USA (as noted above), there was a relative dearth of literature for the emergency levels of service across the energy, telecommunications, and transport sectors. This is where the action research methodology worked so well, in that it enabled a practitioner to investigate a new dynamic in a safe research environment with knowledgeable interviewees and workshop participants.

The original research was carried out through 30 interviews, which allowed for the views of the research participants to be aired on an individual basis. A community workshop testing the concept of PELOS confirmed that the concept could be understood, and was useful, to the layperson. The final workshop, held with emergency managers and critical infrastructure providers, allowed the key stakeholders to see the results of the interviews and understand each other’s perspectives, and discuss the finalisation of the ‘operationalised framework’.

The potential conflict of interest that was generated through the action research methodology approach, namely acting as both researcher and as colleague of the interviewees was addressed

through the process indicated in the high-risk ethics approval (see Appendix 2). This meant that each interview was effectively split into two sections, the first section focussing on the research and theoretical issues, the second section focussing on Wellington Lifelines Group issues. This position was not questioned by any of the research interviewees or participants, however that does not mean that it was not an issue. Johnsen and Normann (2004) faced a more challenging conflict of interest in conducting action research on a regional innovation project in the South of Norway, where the researchers' roles conflicted with the outputs of their work. In their case, they believed that the action researcher has a legitimate right to abandon collaboration and join public deliberation on the impacts of the project. Such an extreme was not necessary in this thesis as the information gathered in the interviews, and the agreement of the Wellington Lifelines Group members to publish the PELOS framework, made it clear that there was not a conflict or need to abandon collaboration.

### 8.3 Revisiting research questions

The research questions for this study were (Section 1.4):

- Can a framework for, and including, emergency levels of service be created that aligns with international literature and best-practice in the relevant sectors?
- What is needed to develop a framework, relevant to the Wellington region, to define and order planning emergency levels of service, that would allow interpretation by key stakeholders?
- What 'planning emergency levels of service' for each infrastructure sector could be defined, relevant to the Wellington region?

Each of the above questions will be addressed, in turn:

#### 8.3.1 Can a framework for emergency levels of service be created...

The literature review found texts that supported the concept of the creation of PELOS, but there were few examples of where such exercises had been carried out (Oregon Seismic Safety Policy Advisory Commission, 2013; Poland, 2008; Washington State Seismic Safety Committee Emergency Management Council, 2012). The literature review supported the

creation of the preliminary framework, which was developed into the operationalised framework presented in Section 5, Paper 2. Essentially, therefore, the answer to the first research question is ‘yes’, such a framework can be created. The key learnings from the literature review were that the sector-specific literature (for energy, telecommunications, transport, and water) found a great deal of information about modelling and analysis of networks, but few concrete examples of levels of service that had been chosen and adopted, with one example in the water sector being the only exception (Wellington Water, 2018b). This abundance of modelling and theoretical literature, but relative absence of practical examples, put a greater onus on the original research of this thesis to create a novel framework. While the water sector has excellent evidence-based approaches, albeit developed for developing world and emergency contexts based on human rights, the other sectors (energy, telecommunications, transport) had very little evidence, or at least any literature may be undocumented. The water evidence being focussed on developing world and emergency contexts, focussed on human rights, means that the resulting PELOS may, or may not, be relevant to the Wellington region. Are most members of the community able to collect their water from up to 1km away? Do they have enough containers at home to carry the water? How are the vulnerable catered for? While these questions are relevant to the water sector, the PELOS for the other sectors also require testing against the communities’ needs. Is it acceptable for the community to be without networked electricity for up to three months? With that level of service, would the community relocate out of the region anyway, making ‘all’ of the PELOS for the Wellington region less relevant? All these issues deserve research to answer these follow-on questions (see Section 8.5).

What this research could answer, however, was what PELOS the critical infrastructure entities could have as their first targets for the delivery of services in an emergency. These PELOS are locally grounded from a collaborative research approach. The value of such grounded collaboration is evident from the work of Baker et al. (1998) and Asman et al. (n.d.), and from the New Zealand context, Beca (2021), which was borne out in the results of this research. The framework is thus useful as a ‘first iteration’ of a framework, to inform the communities and the emergency management sector of what may be delivered for infrastructure services in an emergency event. While no further iterations are currently anticipated, these could be carried out through future projects by the Wellington Lifelines Group. This research enables such outputs, and points towards the next steps of research to better understand how the communities may interface with, or adapt to, such PELOS.

### 8.3.2 ‘What is needed to develop a framework...?’

The second research question was: “What is needed to develop a framework, relevant to the Wellington region, to define and order planning emergency levels of service, that would allow interpretation by key stakeholders?”

The key responses to this question were developed in the original research and addressed in ‘paper 3 – creating a ‘planning emergency levels of service’ framework – a case study’. In addition to the development of a more generic (preliminary) and locally focussed framework the author realised that there were themes beyond the LOSs in the framework themselves that needed to be addressed in order for a framework to be successful.

The first aspect, prior to any definition of PELOS, is to understand the hazardscape of the region under study. This fundamental step is required for several reasons. Firstly, it provides the original reason for considering the delivery of infrastructure services in a hazard event. Key aspects that need to be considered are the nature of the hazard event (flooding, shaking, ash fall), and therefore how the services would be impacted, and the scale of the hazard event, informing likely infrastructure outage times. These aspects will inform the scale of the impacts from the hazards and the potential need to create a framework of PELOS. This does not, however, imply that different PELOS are required for each scenario, as the impacts of the hazard may be common to different hazards – for example leading to power and water outages. The difference is the duration of the outages, hence having a common position on the scale of the impacts. This aspect is addressed in Section 6.5.3.2.

Secondly, and related to the first point (also addressed in Section 6.5.3.2, an understanding of the likely infrastructure outages from such a hazard event is critical to understanding the scale of the loss of services. This requires work (carried out in the Wellington region by the Wellington Lifelines Group (2019) to quantify such outages. Will road access be impacted, and therefore the ability for other infrastructure entities to respond, and the ability for services such as food deliveries be disrupted? Such outage times do not necessarily impact the choice of planning emergency services. For example, the PELOS for water may be the WHO ‘basic access’ standard (World Health Organization, 2003), whatever the nature and scale of the hazard. However, the choice of PELOS for access to food, will depend to some degree on the anticipated outages for road access following an event. If road access is likely to be disrupted for only a short time (hours or days), a shorter time to resume food deliveries may be chosen,

or if only some roads may be impacted, the need for community members to walk or cycle to the supermarket or distribution point may be minimised. Understanding the infrastructure outages and their interdependencies (Wellington Lifelines Group, 2019) will inform the choice of PELOS.

Thirdly, creating a framework of infrastructure PELOS is only possible when there is collaboration between key stakeholders (e.g., for action research, McNiff (2013)) – in the case of this research, the emergency management and infrastructure professionals of the Wellington region. The Wellington Lifelines Group provided an excellent vehicle for such collaboration and discussions on creating the framework. While the motivations to engage with this research, and constraints imposed upon stakeholders to be able to consider levels of service, are different for each stakeholder, the willingness to engage in this research (and Wellington Lifelines Group project) was a key aspect in the creation of the framework. This aspect is considered in more detail in Section 6.5.4.

Fourthly, an understanding of the literature is necessary to create a framework. Other frameworks such as the NIST group of frameworks (National Institute of Standards and Technology, 2016; Oregon Seismic Safety Policy Advisory Commission, 2013; Poland, 2008; Washington State Seismic Safety Committee Emergency Management Council, 2012) provide models for creating frameworks for PELOS. Other texts provide highly researched and understood information on individual levels of service (World Health Organization, 2003), however only a few cells in the framework are informed by such well researched standards. For the power, road access and food access PELOS, there is a great deal of research and advice, but very few firm recommendations or standards, particularly ones that would be relevant to a high-income context such as the Wellington region. To develop a framework relevant to the Wellington region, it is necessary to be informed on what arguments, or information is available, regarding the choices of PELOS.

Finally, a key aspect, one that is not covered in detail in this thesis, that is required to develop a PELOS framework for the Wellington region is a willingness to engage, and recognise that whatever levels of service are developed, there will be counter-arguments. As one interviewee, quoted in paper 3, stated:

“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).

As highlighted in Section 4.7.3, almost whatever level of service is chosen, some members of the community will not be able to interface with those levels of service. For example, some members of the community will not be able to walk to the supermarket to collect food, for reasons of age or disability. Some will be able to walk short distances, some may be able to walk or cycle large distances. Choosing a level of service with key stakeholders is therefore not necessarily a science, but an exercise in working out a starting point for discussion.

Strongly related to the above point, the willingness to engage, is having a space to carry out such discussions. This is largely addressed within the third point, above, with the vehicle of the Wellington Lifelines Group providing that space. However, the willingness of the governance of that group, and other emergency management structures in the Wellington region to engage in such conversations have translated the willingness to the creation of a framework.

The above are the functional, or process, requirements needed to develop a framework of infrastructure PELOS for the Wellington region and provide an answer to the first research question. What levels of service could be defined should then be addressed.

### 8.3.3 ‘What planning emergency levels of service could be defined...?’

The third research question was: “What ‘planning emergency levels of service’ for each infrastructure sector could be defined, relevant to the Wellington region?”

This research question is partially answered in the section above, which focussed on the process for the creation of the PELOS. The actual PELOS developed in this thesis are presented in Section 5, Paper 2, which contains the operationalised framework containing the levels of service. These provide the main output of this research. The adoption of PELOS could be done voluntarily by a single utility, as was carried out by Wellington Water (2018b), by a sector as done by the Sphere Association (2018), either locally (Wellington Water) or internationally (Sphere Association). Such PELOS have driven Wellington Water’s emergency planning and implementation (Wellington Water, n.d.-c) and have been fundamental in understanding what an emergency response to a water outage should comprise (example, Oxfam (n.d.)).

Were there other types of infrastructure that could, or should, be included in a PELOS framework? While most of the infrastructure types were included in the framework, there is potential to include the rail network, which was not included here due to the temporary unavailability of interviewees to discuss the concept with. Other sectors that could, in future, be included are those sectors that other countries consider to be ‘critical infrastructure’, such as, for example, ‘dams and flood defence’, ‘health’ and food supply and distribution (Organisation for Economic Co-operation and Development, 2019). The process used in this thesis to establish new PELOS could be used in those other countries for the sectors not already covered by the framework in this thesis.

In addition to the considerations above, the production of the mapping tool, detailed in Section 7, paper 4, enabled a relatively quick and intuitive assessment of where the proposed PELOS were modelled to be achievable, and where they were not likely to be achievable. It is this visual output from this study that appears to most capture the attention of the emergency management professionals engaged in this research. This visual demonstration is the key aspect that answers the question “What ‘planning emergency levels of service’ for each infrastructure sector could be defined, relevant to the Wellington region?”. As will be seen from that paper and mapping, according to the modelling carried out by GNS Science for the Wellington Lifelines Group (2019), few of the PELOS are achievable across the region. For example, in some areas of the region, people would have to transport water from more than 1km away from the home, walking distances between supermarkets and the home are more than 2km and some supermarkets will not be opened within 7 days of a rupture of the Wellington fault. Such insights, gained quickly from the mapping tool, are a powerful way to convey the impact at both regional level and at a household level of a rupture of the fault.

## 8.4 Limitations

There are several limitations of this thesis. Most clearly, a limitation of the infrastructure PELOS produced in the operationalised framework (Section 5.7), is that many of the developed levels of service (for power, road access, food and LPG, broadcast) are ‘best guesses’ put together by emergency management professionals and infrastructure entity staff. They are supported, where possible, by good evidence in the literature however, like the highly researched WHO ‘basic access’ to water standard, they provide a basis for analysis, and a basis

for planning for emergency events. This is an aspect of the wider concept of ‘levels of service’ (as used by infrastructure entities, see Section 1.1), where a level of service is proposed based on the information available, and the infrastructure entities use it as a goal for delivery. This aspect of the concept means that the chosen level of service may be argued against, in that it may be considered by some to be either too high or too low. Despite this, it does not change either the approach taken to this research, or the aim of the research to identify PELOS. It does mean, however, that future iterations of the PELOS in the operationalised framework could be carried out, refining the PELOS, where they are thought to be either too ‘easy’ or too onerous to achieve.

The number of interviewees (30) used in this research was considered by the lead author to be sufficient to bring out the key aspects of opinions of the concept of PELOS (i.e., saturation) and was sufficient to gain a coverage of all key infrastructure sectors. Further, the range of interviewees covered local government, central government, emergency management and infrastructure entity staff. While this effectively gave a blanket coverage of organisations and key stakeholders, there would have been value in continuing to find more voices to cover all sectors (for example, no interviewees were found for the ‘broadcast’ sector), with more voices potentially uncovering new aspects or new opinions on the concept.

The operationalised framework produced in this thesis is deliberately kept to a level where it can inform moderate- and large-scale emergency responses. This means that smaller events that impact infrastructure for less than, say, a few days receive less treatment (it is possible that the PELOS articulated in the operationalised framework could be delivered for just a few days), and long-duration responses and recovery work receives less attention, being dealt with by a statement in the framework referring to ‘a new normal’. While greater fidelity could be achieved through expanding the concept into levels of service covering the first hours, or days, or covering from the third month through to ‘x’ years after the event, such work may not provide significant benefit for informing either the early response or long-term recovery. This is because the short-term events can often be dealt with through business-as-usual type responses (i.e., to short term floods or windstorms) and, as one interviewee noted, recovery planning holds greater uncertainty, including lack of knowledge (pre-event) of what areas may be red-zoned (as occurred following the Canterbury sequence of earthquakes), uncertainty of timescales and uncertainty of the ‘on-the-day’ response capabilities and capacities of the responding agencies for infrastructure services. For these reasons, the framework presented in

this thesis may be considered to cover the key aspects of response and early recovery to moderate and major events.

While this research is heavily centred on the delivery of infrastructure services, it only gives moderate attention to the end-users, normally the members of the community. The intention of the thesis was not to address ‘all’ aspects of PELOS for both infrastructure entities and members of the community, rather to create a starting point for understanding the linkage between infrastructure service delivery in an emergency and the needs of the community. As will be seen in the next section on future research suggestions, it is evident that this research brings into sharper focus the needs of the end-users, the community members impacted by a hazard event.

This research does not start to address follow-on questions around emergency planning or physical mitigations such as improving retaining walls on roads or toughening water pipe networks. This research is intended to inform such potential follow-on work, not address it directly.

The mapping presented in Section 7 relates to only a single hazard – a rupture of the Wellington fault. This is because there is available infrastructure outage modelling carried out, using a rigorous process by GNS Science, available in the Wellington Lifelines Group Programme Business Case (Wellington Lifelines Group, 2019). This modelling provides a simple, high-quality, baseline to analyse against. Further value for this thesis could be gained by using other rigorous modelling carried out for hazards (e.g., for tsunami or flood events). At the time of writing this thesis, the available information was used, but if other data became available in the future, there would be value in carrying out a similar mapping for other hazards.

As for any project, the author will have a research bias, however the choice of action research as a methodology is seen as a means of mitigating such bias. This is in alignment with the acknowledgement that this research falls under the critical realist research philosophy, as outlined in Section 2.2.

In accordance with the action research philosophy, the author conducted research on a work project, with a group of people that he already works with (WREMO and the Wellington Lifelines Group (WeLG)). Due to this dynamic, there was a raised potential for a conflict of interest to develop, should the outcomes of the research conflict with existing processes or procedures of the members of the WeLG members. Further, during the interview process, interviewees might believe that their organisation would be committing to outcomes that would

cause their organisations expense or other commitments. This dynamic was highlighted through the ethics approval process, for which a ‘high risk’ ethics application was prepared, through the Massey University Ethics Committee process. In the author’s opinion, the interviewee dynamics did not create any fundamental flaws in the research or its outcomes (which would have been highlighted in the interview results). The full ethics approval is included in Appendix 2, with the pre-interview information and form presented in Appendices 3, 6 and 7.

The above limitations are a mixture of methodological and contextual issues. The methodological issues (number of interviewees, use of the action research methodology) have been addressed, where possible, through systems put in place (checking by academic supervisors and applying for ethics approvals through a formal process). The contextual issues (limitations of the concept of ‘levels of service’ and availability of modelling data for only one hazard event) cannot be addressed within the confines of this thesis. The above aspects are not considered, by the lead researcher, to be fundamental flaws in the work presented in this thesis.

## 8.5 Future research suggestions

One aspect that has become apparent through the work on this thesis is that the framework of PELOS makes clearer the impacts and consequences to the community of reduced levels of service from the infrastructure entities in the Wellington region, following a major hazard event. For example, one interviewee noted that Urban Search and Rescue responders had to get to collapsed buildings quickly after an earthquake and therefore the roads had to be open to enable that, when the outage data and the PELOS developed with the outages in mind demonstrate that this will not be possible. Further, discussions the author has had in the Wellington region demonstrate that many people have unrealistic expectations regarding how long power outages following a major earthquake will last. When seeing a proposed PELOS, some people have started to strategise how they would work without an infrastructure service for an extended period. The consequences to the community of lower levels of service are, the author believes, currently under-researched. Also, how infrastructure services can be restored faster also needs consideration. The loss of services will also impact how the emergency services perform their functions – across police, fire response and medical responses (ambulance). The impacts on the community are, perhaps, the most significant of the aspects

that require follow-on research. While some literature is available (see below), there appears to be a relative lack of understanding of this aspect, internationally. How will the communities of the Wellington region interface with such levels of service? Collecting water and food from distance, at a time potentially without power, will be challenging for many. All these aspects would be valuable to research further. Unfortunately, the scope of this thesis has not allowed for detailed research into these aspects, so they are listed here for future consideration.

#### 8.5.1 Evacuation and adaptation decisions – when would people leave their homes and how would they adapt to infrastructure outages?

At what point would people leave their homes in an emergency event for other accommodation? How would they adapt to prolonged infrastructure service outages? Would they self-evacuate when the walking distance to collect water is greater than a certain distance? When food stocks run out and the distance to supermarket is greater than a certain distance? When power, water and food access are compromised (but still available) but the school has shut? When there are aftershocks, and ‘Uncle Jim’ has a spare room in Hamilton? What evacuation and adaptation decisions exist for people that motivate them to move from their homes? Such research would provide an indicator of how likely it is that people would evacuate, faced with some of the PELOS developed in this thesis. It is likely that different people would have different ‘tipping points’, meaning that there would be a range of responses and behaviours, based on the same level of service. Work by Rachel Davidson et al (Abbou et al., 2022; Davidson et al., 2022; Stock et al., 2022) has provided some excellent theory on this issue. Some texts investigate the impacts of infrastructure outages, some study relatively short-term outages (a week, or less) (Bachman & Saul, 2021; Ghanem et al., 2016; Palm, 2009), which is below the scale of event covered in this thesis. Some texts are well researched and written, but focussed on low income environments (Rosen & Vincent, 1999; Smadi et al., 2018; Smiley, 2016; Thompson & Cairncross, 2002; White et al., 1972) which are perhaps only tangentially relatable to the Wellington region community.

This research could be tested against some practical research, including interviewing people that have been impacted by prolonged infrastructure outages, for example as a result of a major storm or recent earthquake. Clearly, ethics approvals would be required for such practical aspects.

Research questions could be sorted into ‘primary’ (key/priority) and ‘secondary’ (lower priority, but still desirable to be answered) questions. The primary questions are: what are the ‘tipping points’ at which Wellington residents would wish to move out of their residences due to infrastructure outages (or the adaptations they would use to adjust to such outages); do the Wellington region’s ‘planning emergency levels of service’ deliver sufficient services to enable a significant proportion of the population to remain at home, following an event?; and are different demographics (age, gender, ethnicity) a factor in individuals’ ‘tipping points’? The secondary questions are: is there a particular critical infrastructure that is the dominant determinant of whether a resident would choose to relocate from their home (at least temporarily); how do the ‘tipping points’ inform the (assume two-year) recovery process; how do these ‘tipping points’ impact business in the Wellington region.

#### 8.5.2 What are the walking distances Wellington residents could manage in an emergency event?

The PELOS framework developed in this thesis indicates that residents of Wellington could be walking significant distances following a major earthquake to access food, medical aid, water, and access to information. What are the distances that residents of the Wellington region could achieve to access these services? What of those that cannot walk far, and depend on the mobile (and available) members of the community to assist them? And do the residents of the Wellington region generally have containers at home that could be used to transport the water home? Some information does exist to part-answer these questions which describe how long (but rarely how far) people walk per day in the Wellington region (Ministry of Transport, 2015, n.d.; Waka Kotahi New Zealand Transport Agency, 2021), or how community transport was organised following the Great East Japan Earthquake (Nakanishi et al., 2014). Field research could be conducted to work out how far residents either can, or feel they could, walk to access services in a major event.

#### 8.5.3 How quickly does the fuel run out, and how is it re-supplied?

Following a major earthquake affecting the Wellington region, the first emergency management action for fuel supply is to restrict supply to priority users only (stopping supply

to members of the public). It is likely (as seen from the Wellington Lifelines Group (2019) report) that fuel supply will run out before re-supply can be managed. Which are the ‘most’ critical functions for fuel re-supply? How could re-supply be made quicker (ship to shore deliveries)? What happens after the fuel runs out and before re-supply? This research could be carried out through understanding how fuel outages have been managed following road disruption in other regions or countries, and understanding what mechanisms might be available for emergency fuel supply (e.g. ship to shore systems). Further, understanding the critical facilities that will require fuel to function (hospitals, telephone exchanges etc.) will help identify the impacts of such fuel outages on the population.

## 8.6 Potential replication of a similar framework for other regions of New Zealand, or internationally

How could this framework be replicated in other regions? This aspect is detailed in Section 6 (paper 3) where the process taken in creating a PELOS framework is described (Section 6.4.2), with Figure 6 providing an overview of that process. Of key concern, however is the issue of ‘who should lead the creation of a PELOS framework?’ Section 6.6.2 outlines that, for this research/project, the Wellington Lifelines Group and the Wellington Region Emergency Management Office provided relatively independent bodies that could look across both emergency management and infrastructure sectors (energy, telecommunications, transport, water) to facilitate this work.

As outlined in Section 6.5.3.2, the choice of hazard to be used as the basis for the creation of the framework is relevant to the region that creates a framework, however the choice of hazard scenario was found to be less important than the choice of the scale of the hazard identified for analysis. For example, one interviewee stated that the ‘bigger challenges are around the bigger events... as the system is able to absorb those disruptions to smaller events’. However, the choice of hazard scenario, in this research, gave interviewees and participants an idea of the scale of damage and infrastructure outages that could be envisaged/analysed for PELOS. Therefore, the choice of a major event was key as providing a scale of outage, but the choice of ‘exact’ hazard scenario turned out to be of lesser consequence.

In addition to the above, any region may use the literature review conducted in Section 4, and the operationalised framework presented in Section 5.5 as a basis for identifying their own PELOS.

Using the process identified in Section 6, other regions or countries could replicate the same process and create their own frameworks of PELOS.

## 9 Conclusion

In conclusion, we know that the Wellington region is vulnerable to hazard events including, for example, earthquakes, tsunamis and storms. Due to the location of the Wellington fault bisecting the Wellington region, hazards and impacts of a rupture of the Wellington Fault are well-established (GNS Science, 2020; Stewart et al., 2016; Wellington Lifelines Group, 2012, 2019). Some of the resulting modelled outages could be lengthy, for example there could be a lack of networked electricity supply for three to six months (Wellington Lifelines Group, 2019, p. 167).

In this thesis a framework of targets for the restoration of infrastructure services, or ‘planning emergency levels of service’ (PELOS) has been developed, initially through a literature review and expert elicitation (Section 4, Paper 1), and then from interviews and workshops with key stakeholders. The resulting ‘operationalised framework’ (Section 5, Paper 2) covers most of the critical infrastructure services in the region.

The process taken in forming the PELOS framework is detailed in Section 6, Paper 3. This is given in sufficient detail that other regions of New Zealand, or internationally, could follow the same processes to create their own frameworks. Key themes regarding the concept of PELOS are also explored in that section, including: interdependencies between infrastructure sectors, vulnerable communities and how PELOS accommodate, or not, those communities, emergency planning considerations of PELOS, how choosing a hazard event for creating the framework is critical, the willingness of key stakeholders to collaborate on the creation of the framework and, finally, the flexibility/adaptability of the delivery of services.

The mapping tool that allows a visualisation of a comparison between PELOS and previously modelled infrastructure outages expected from a rupture of the Wellington Fault was presented in Section 7, Paper 4. This tool is one of the key outputs of this thesis, allowing both emergency planners and the public to visualise where there may be gaps between PELOS and the delivery of infrastructure services, post-event.

The research approach and methodology used in this thesis was described in Sections 2 and 3. The research was grounded in the critical realism paradigm, which aligns with the action research philosophy. This use of this philosophy was key, as the author of this research was working with key stakeholders in his existing work to investigate an issue dynamic that was relevant to this work. The success of this approach is outlined in Section 8.2. Whilst it did

require a conflict of interest to be managed, as highlighted in the high-risk ethics approval process, it provided a clear research process for the author to follow.

Apart from the mapping webtool, noted above, the other key output of the thesis, the operationalised PELOS framework has been used as the basis of Clause 57 of the Emergency Management Bill (2023), where “a critical infrastructure entity must establish and maintain planning emergency levels of service in respect of its critical infrastructure.” It will be interesting to see, firstly, whether the concept will be taken forward into legislation, and if so, whether the intended goals of the concept, to better inform the community of potential outages, to provide information to emergency planners for what impacts there may be on the community and to provide information to the critical infrastructure entities on where key vulnerabilities might need investment to reduce outage durations.

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## **Appendices**

Appendix 1: Statement of contribution sheets for submitted journal papers

Appendix 2: Ethics notification(s)

Appendix 3: Information sheet: interviews

Appendix 4: Participant consent forms: interviews

Appendix 5: Structured interviews: questions

Appendix 6: Information sheet: workshops

Appendix 7: Participant consent forms: workshops

Appendix 8: Structured workshop agenda

Appendix 9: Exemplar creation of a planning emergency level of service: Creating a post-earthquake emergency sanitation plan for the Wellington region, Aotearoa New Zealand

Appendix 10: Paper 4, mapping tool – supplementary information

# Appendix 1: Statement of contribution sheets for submitted journal papers

Paper 1: Mowll, R., Becker, J., Wotherspoon, L., Stewart, C., Johnston, D., Neely, D. P., Rovins, J., & Ripley, S. (2022). Infrastructure planning emergency levels of service for the Wellington region, Aotearoa New Zealand - a preliminary framework. *International Journal of Disaster Risk Reduction*, 72, 2-16. <https://doi.org/doi.org/10.1016/j.ijdr.2022.102843>

**Richard Mowll:** Conceptualization, Methodology, Investigation, Writing – original draft, Project administration. **Julia Becker:** Supervision, Writing – review and editing. **Liam Wotherspoon:** Supervision, Writing – review and editing. **Carol Stewart:** Supervision, Writing – review and editing. **David Johnston:** Supervision, Writing – review and editing, Funding acquisition. **Dan Neely:** Writing – review and editing. **Jane Rovins:** Supervision, Writing – review and editing. **Sam Ripley:** Writing - reviewing and Editing.

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## STATEMENT OF CONTRIBUTION DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Richard Mowll
Name/title of Primary Supervisor:	Julia Becker
In which chapter is the manuscript /published work:	Chapter4/Paper1
Please select one of the following three options:	
<input checked="" type="radio"/> The manuscript/published work is published or in press <ul style="list-style-type: none"> <li>Please provide the full reference of the Research Output: Mowll, R., Becker, J., Wotherspoon, L., Stewart, C., Johnston, D., Neely, D. P., Rovins, J., &amp; Ripley, S. (2022). Infrastructure planning emergency levels of service for the Wellington region, Aotearoa New Zealand - a preliminary framework. <i>International Journal of Disaster Risk Reduction</i>, 72, 2-16. <a href="https://doi.org/doi.org/10.1016/j.ijdr.2022.102843">https://doi.org/doi.org/10.1016/j.ijdr.2022.102843</a></li> </ul>	
<input type="radio"/> The manuscript is currently under review for publication – please indicate: <ul style="list-style-type: none"> <li>The name of the journal:</li> <li>The percentage of the manuscript/published work that was contributed by the candidate:</li> <li>Describe the contribution that the candidate has made to the manuscript/published work: Lead on conceptualisation, methodology, formal analysis, investigation, writing (original draft preparation), writing (editing) and project administration (submission of paper to journal and working through to acceptance/publication).</li> </ul>	
<input type="radio"/> It is intended that the manuscript will be published, but it has not yet been submitted to a journal	
Candidate's Signature:	
Date:	21 July 2023
Primary Supervisor's Signature:	
Date:	21-Jul-2023

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Paper 2: Mowll, R., Becker, J. S., Wotherspoon, L., Stewart, C., Johnston, D. M., & Neely, D. (2023b). Infrastructure planning emergency levels of service for the Wellington Region, Aotearoa New Zealand: An operationalised framework [Advanced online publication]. Bulletin of the New Zealand Society for Earthquake Engineering.

**Richard Mowll:** Conceptualization, Methodology, Investigation, Writing – original draft, Project administration. **Julia Becker:** Supervision, Writing – review and editing. **Liam Wotherspoon:** Supervision, Writing – review and editing. **Carol Stewart:** Supervision, Writing – review and editing. **David Johnston:** Supervision, Writing – review and editing, Funding acquisition. **Dan Neely:** Writing – review and editing.

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In which chapter is the manuscript /published work:	Chapter/Section 5
Please select one of the following three options:	
<input checked="" type="radio"/> The manuscript/published work is published or in press <ul style="list-style-type: none"> <li>• Please provide the full reference of the Research Output: Mowll, R., Becker, J. S., Wotherspoon, L., Stewart, C., Johnston, D. M., &amp; Neely, D. (2023). Infrastructure planning emergency levels of service for the Wellington Region, Aotearoa New Zealand: An operationalised framework [Advanced online publication]. Bulletin of the New Zealand Society for Earthquake Engineering.</li> </ul>	
<input type="radio"/> The manuscript is currently under review for publication – please indicate: <ul style="list-style-type: none"> <li>• The name of the journal:</li> <li>• The percentage of the manuscript/published work that was contributed by the candidate:</li> <li>• Describe the contribution that the candidate has made to the manuscript/published work: Lead author</li> </ul>	
<input type="radio"/> It is intended that the manuscript will be published, but it has not yet been submitted to a journal	
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Primary Supervisor's Signature:	
Date:	13/10/2023

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Paper 3: Mowll, R., Becker, J., Wotherspoon, L., Stewart, C., Johnston, D., & Neely, D. (2023a). Creating a 'planning emergency levels of service' framework - a silver bullet, or something useful for target practice? *Resilient Cities and Structures*, 2(2), 1-12. <https://doi.org/10.1016/j.rcns.2023.05.002>

**Richard Mowll:** Conceptualization, Methodology, Investigation, Writing – original draft, Project administration. **Julia Becker:** Supervision, Writing – review and editing. **Liam Wotherspoon:** Supervision, Writing – review and editing. **Carol Stewart:** Supervision, Writing – review and editing. **David Johnston:** Supervision, Writing – review and editing, Funding acquisition. **Dan Neely:** Writing – review and editing.

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<input type="radio"/> It is intended that the manuscript will be published, but it has not yet been submitted to a journal	
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Paper 4: Mowll, R., Anderson, M. J., Logan, T. M., Becker, J. s., Wotherspoon, L., Stewart, C4., Johnston, D. M., & Neely, D. (2023). A new mapping tool to visualise critical infrastructure levels of service following a major earthquake. Manuscript submitted for publication.

**Richard Mowll:** Conceptualization, Methodology, Investigation, Writing – original draft, Project administration. **Mitchell Anderson:** Writing – original draft. **Tom Logan:** Supervision, Writing – review and editing. **Julia Becker:** Supervision, Writing – review and editing. **Liam Wotherspoon:** Supervision, Writing – review and editing. **Carol Stewart:** Supervision, Writing – review and editing. **David Johnston:** Supervision, Writing – review and editing, Funding acquisition. **Dan Neely:** Writing – review and editing.

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<input type="radio"/> The manuscript is currently under review for publication – please indicate: <ul style="list-style-type: none"> <li>The name of the journal:</li> <li>The percentage of the manuscript/published work that was contributed by the candidate:</li> <li>Describe the contribution that the candidate has made to the manuscript/published work: Lead on conceptualisation, methodology, validation, formal analysis, investigation, data curation, writing original draft, writing review and editing and project administration. Mitch Anderson was lead on software and visualisation and on writing section 7.4.2.</li> </ul>	
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## **Appendix 2: Ethics notifications**

### **Infrastructure planning minimum levels of service for the Wellington region – ethics approval application**

#### **Project summary**

There are known vulnerabilities in the various lifeline utilities networks in the Wellington Region, which make them prone to damage and disruption following hazard events. These are across the energy, telecommunications, transport (and therefore also food delivery) and water sectors. The vulnerabilities have been documented in various documents (Wellington Lifelines Group, 2012, 2019; Wellington Region Emergency Management Office, 2019) (WeLG, WREMO). The residents of the region need access to the utility services, to continue to live in the area, or at least survive until they can move out of the affected area. If the residents' needs can be defined, the gap between needs and delivery of services by the lifeline utilities can then be defined at 'suburb level' for key scenarios. The identification of any gaps will aid the lifeline utilities and emergency management sector to refine emergency planning for those people that the modelling suggests will be affected by the potential disaster. Similarly, this information would be useful to the individuals (and communities) themselves, setting expectations of delivery and allowing detailed local emergency planning to take place. This research aims to set preliminary 'planning minimum levels of service' (PMLOS), model them against infrastructure outages and present a set of mappings that show any gaps of delivery. The data collection will be carried out primarily through interviews with emergency management and utility provider staff, and secondarily with at least one community focus group (who are members of the WREMO's voluntary focus group). One key aspect of this data collection is that the lead researcher is the Project Manager of WeLG and the Lifeline Utilities Co-ordinator for WREMO, with existing working relationships with the interviewees. This creates issues of delineating the researcher's role as researcher from his 'business as usual' roles.

**Describe the peer review process that has been used to discuss and analyse the ethical issues present in this project**

- A Massey staff member (Julia Becker) along with researcher Richard Mowll, reviewed the Code of Ethical Conduct.
- A plan of the research to be carried out which addressed the Code of Conduct was discussed within the research team and with external examiners at the confirmation presentation for this research. The confirmation committee comprised of Dr Raj Prasanna (Chair), and the research student's research supervisors, who are Dr Julia Becker (Lead supervisor), Professor David Johnson, Dr Jane Rovins (all Massey University) and Associate Professor Liam Wotherspoon (University of Auckland). The external examiners were Dr Germana Nicklin and Associate Professor Carol Stewart (who is now a supervisor for this research.)
- Massey University staff members reviewed the methodologies with the key principles in mind (i.e. respect for persons; minimisation of harm; informed and voluntary consent; respect for privacy and confidentiality; avoidance of deception; avoidance of conflict of interest; social and cultural sensitivity; justice) and found that the proposed research had considered and accounted for these aspects. The Confirmation Committee for this research highlighted that the working relationship that the lead researcher has with the interviewees meant that a full ethics proposal should be applied for, to allow for full consideration of the ethical aspects of this research.
- Application was submitted to the Massey online ethics portal, with attention to any risk questions given via the screening process.

**List the ethical issues considered and explain how they have been addressed**

This research will follow the 'action research' methodology, in which the lead researcher is working within his 'business as usual' roles of 'Project Manager of the Wellington Lifelines Group' and 'Lifeline Utilities Co-ordinator' for the Wellington region. As such, the researcher has existing working relationships with the interviewees.

The ethical issues considered included: minimisation of harm, avoidance of deception, respect for persons, avoidance of conflict of interest, and social and cultural sensitivity. All participants will be made aware that if they decide to not to contribute to the research, then any contributions

will be excluded from data analysis and write up. All participants will be informed at the start of the discussions that they are not required to contribute anything that would make them uncomfortable. Additionally, all participants can withdraw their participation at any stage of the research process. In terms of benefits, the research is designed to support emergency management planning and understandings of wider disaster response, and collection of data will add to national understanding about how regions and utilities can be better supported following a disaster.

One of the key aspects is to create a clear distinction between the interviewer's role as researcher, and his role as practitioner. This will be achieved through the documentation to be sent to interviewees and workshop participants.

Interviews are based on the discussion of practical information, not personal information. The discussions will be of a practical nature, so should not be of a personal or distressing nature. However, the nature of the discussion points will potentially affect what the interviewees may consider as reputational risk to their organisations. This aspect will be addressed through a question in the structured interview questions that will give the interviewees the option not be part of, the project outputs.

### **The aim of the project**

The primary aim of this research is to create a framework that holds a variety of PMLOS. One example of a PMLOS is Wellington Water's '20 litres of water, per person, per day, within 1km of the dwelling', for during a major water outage. It is intended that similar PMLOS be developed for the energy, telecommunications and transport sectors. This will be done firstly through the creation of a theoretical framework, developed from literature by expert practitioners. An operational framework will subsequently be developed from data collected from workshops and interviews conducted with key stakeholders (the ethical issues of which are the purpose of this document).

The secondary aim of this research is to map the developed PMLOS against modelling carried out for the Wellington region on infrastructure vulnerabilities. Once done, the modelling will help inform whether various utilities will perform to the developed PMLOS, mapped at suburb-level. This will inform community members, emergency managers and infrastructure providers on what may be delivered by the utilities following a disaster.

## **Background of project**

The measurement of ‘resilience’ is a task that has occupied various researchers and organisations (International Organization for Standardization, 2019; Rockefeller Foundation & Arup, 2014; United Nations Office for Disaster Risk Reduction, 2017) for around a decade. From these studies, in the researcher’s opinion, the understanding of ‘resilience’ does not appear to have advanced. Meanwhile, the understanding of hazards facing the Wellington region has advanced, particularly regarding the vulnerability of infrastructure (Wellington Lifelines Group, 2012, 2013, 2019).

The Wellington Region Emergency Management Office (WREMO) has included a set of tasks in its ‘Group Plan’ (a description of its tasks for a period of time) as creating a set of PMLOS and assessing it against vulnerabilities (Wellington Region Emergency Management Office, 2019). The researcher works for WREMO as the Wellington region’s ‘Lifeline Utilities Co-ordinator’, a role that involves planning for, and responding to, infrastructure outages in the region. He has held this role since 2011. In this role, he therefore has a unique opportunity to engage with the infrastructure providers and carry out research.

Internationally, there are very few published PMLOS for utilities. The nearest examples are from the Sphere Handbook (Sphere Association, 2018) and from three States in the USA (Oregon Seismic Safety Policy Advisory Commission, 2013; Poland, 2008; Sphere Association, 2018; Washington State Seismic Safety Committee Emergency Management Council, 2012).

The above is a gap that is evident in the literature. The intention is that this gap will be addressed by this research.

## **Outline research/teaching/evaluation procedures including approach / procedures for collecting data.**

Due to the researcher’s role with WREMO, the ‘action research’ methodology is being used for this research. This creates a methodological framework in which to carry out research during a working ‘task’, where the researcher is part of the delivery of the task.

Specifically, regarding the research, the researcher will conduct semi-structured interviews with key stakeholders (expected to be a maximum of 60) that he already engages with regularly

through his work with WREMO. The interviews will be digitally recorded. Once collected, the interviews will be transcribed and coded for analysis.

In addition, one workshop (or two, if the first workshop is unsuccessful in capturing learnings) will be conducted to ascertain whether the proposed PMLOS are understandable to the layperson, and of use in understanding the potential consequences of an emergency event. The workshops will be conducted through group discussion, using semi-structured questions. The researcher will also record the workshop(s). Analysis will be carried out through the comparison of the transcription(s) against the PMLOS and underlying logic of the framework, using coding in NVIVO.

Interviews will be arranged through direct e-mails from the lead researcher to the interviewees. These e-mails will contain the package of information required to set up the interviews, including:

- Participant information sheet.
- Participant consent form.
- Authority for the release of transcripts (not required until after the interviews, but to be sent to interviewees ahead of interviews, to provide full documentation at the start of the process.

Interviews will be conducted either at the places of work of the interviewees, or through online meetings (e.g. Zoom, Teams).

Interviewees will be given the opportunity to view the transcripts from their interviews, and modify them, if they wish.

The community focus group workshop(s) will be arranged through WREMO, who will make arrangements with their standing 'community focus group' for the event. The researcher will provide information, including the participant information sheet and participant consent form, to WREMO for sending to the community focus group prior to the workshop.

**Describe the experience of the researcher and / or supervisor to undertake this type of project. \***

**Richard Mowll** is a PhD student at the Joint Centre for Disaster Research at Massey University. He is the lead researcher working on the creation of a framework of PMLOS. Richard brings experience and working knowledge of the lifeline utilities of the Wellington region, specifically regarding emergency management issues. Richard's passion is working closely in the emergency management sector to deliver best practice outcomes. He brings excellent communication, organisational, analytical and problem-solving skills to all projects, along with the ability to reflect critically, realistically and honestly.

**Dr Julia Becker** is a social researcher at the Joint Centre for Disaster Research at Massey University. Julia undertakes qualitative and quantitative social science research on a range of natural hazard and environmental issues. Her areas of expertise include perceptions, preparedness, community resilience, emergency management and warnings. She has worked extensively in New Zealand on recent events (e.g. Canterbury and Kaikoura earthquakes) and internationally (e.g. U.S, Australia, Japan).

**Prof. David Johnston** is the Director of the Joint Centre for Disaster Research at Massey University, the former Chair of the Integrated Research on Disaster Risk Scientific Committee (IRDR), a programme co-sponsored by the International Science Council (ISC) and the United Nations Office for Disaster Risk Reduction (UNDRR). His expertise is in social responses to pandemics, human responses to natural hazard disasters, crisis decision-making, and the role of public education and participation in building community resilience and recovery.

**Associate Professor Carol Stewart** is a disaster environmental health specialist. Her research interests include environmental health consequences of natural hazards and disasters; volcanic hazard impacts; volcanic ash chemistry; environmental, agricultural and health impacts of volcanic eruptions; developing volcanic ash hazard assessment methods; vulnerability of water and wastewater infrastructure to natural hazards and disasters. Internationally, she is a Deputy Director of the International Volcanic Health Hazard Network ([www.ivhhn.org](http://www.ivhhn.org)); a core member of the Volcanic Ash Impacts Working Group, a commission of IAVCEI, and a member of the World Association of Disaster and Emergency Medicine Oceania Chapter.

**Associate Professor Liam Wotherspoon's** research focuses on both structural and geotechnical aspects of earthquake engineering. Resilience of infrastructure networks (modelling of components, networks and network interdependencies). Geotechnical site characterisation (geophysical characterisation, liquefaction). Soil-foundation-structure interaction and integrated response of structures and foundations (computational modelling and

field testing/monitoring of buildings and bridges). Foundation response (computational modelling, large scale field testing). Heavily involved in post-earthquake reconnaissance investigations during the 2010-2011 Canterbury, New Zealand earthquake sequence and following the 2016 Kaikoura earthquake.

### **Where will the project be conducted?**

Interviews will be conducted across the Wellington region of Aotearoa New Zealand, generally at the places of work of the interviewees. The community focus group workshop will be held at the Wellington Region Emergency Management Office, Thorndon.

### **How many participants will be involved?**

A minimum of 30 and a maximum of 60 participants will be interviewed in face-to-face (or Teams/Zoom) meetings. Further, either one or two community focus group workshops will be held with participants of WREMO's community engagement group of local residents. It is anticipated that each workshop will comprise of around 10 people and will be held over less than two hours.

### **Provide the reason for selecting this number or the statistical justification (if relevant). \***

The proposed PMLOS framework is likely to cover the energy, telecommunications, transport and water sectors. Staff members from each of the relevant lifeline utilities will be interviewed – this accounts for approximately 40 of the interviewees. Additionally, key stakeholders from emergency management (national, regional and local levels) will be interviewed, accounting for a further 15 interviewees. The remainder of interviewees are from key organisations with either an input to, or likely to have opinions on, PMLOS. Given that the research is qualitative in nature, this figure does not have statistical significance, however it does cover the key stakeholders (organisations) that need to be engaged both from a research and WREMO standpoint, to gather sufficient input to the various aspects of the proposed framework, and to reach saturation.

**How will potential participants be identified? \***

The participants from the lifeline utilities and emergency management sectors are the working contacts of the lead researcher at the relevant lifeline utility and emergency management organisations.

As above, the community focus group workshop participants will be from WREMO's 'community focus group', who have a standing voluntary arrangement to participate in WREMO's discussions on emergency management issues.

**How will potential participants be recruited? \***

Interviewees will be recruited by invitation through direct contact from the lead researcher, as they are the lead researcher's key contacts for his role at WeLG/WREMO.

The community focus group workshop participants will be contacted directly by WREMO, as part of the standing arrangement for discussion on emergency management issues. The information package to be sent to the workshop participants prior to the workshop will make it clear that participation in the workshop is voluntary.

**Who will make the initial approach to potential participants? \***

The lead researcher will make the initial approach to the potential interview participants.

WREMO will make the initial approach to the community focus group workshop participants.

**Does the project include recruitment through advertising? \***

No

**Describe any specific inclusion / exclusion criteria to select participants \***

Inclusion (for interviews):

- Existing contact at a lifeline utility for WREMO work.

- Existing contact within emergency management for WREMO work.
- Staff at a key stakeholder that may have important input to a PMLOS framework, such as at key NZ central governmental organisations such as the Earthquake Commission and non-governmental organisations such as the NZ Lifelines Council.

Exclusion (for interviews):

- Those not involved in any capacity with any of the lifeline utilities or emergency management or key stakeholder organisations.

Inclusion (for community focus group workshop(s)):

- Those within the WREMO community group that voluntarily participate in the workshop (once workshop information has been forwarded to them, prior to the workshop).

**Will you be using a screening tool? \***

No

**How much time will the participants give to the project? \***

Up to 60 minutes for interviews, plus up to 120 minutes at a follow-on workshop (that would be part of a 'business as usual' WREMO meeting).

Up to 120 minutes for community workshops.

**Does this match the time provided to the participants on the information sheet? \***

Yes.

**Describe the intended participants \***

From the key stakeholders, the interviewees are adults that work for the lifeline utilities, in emergency management or at one of the key central government or relevant non-governmental organisations. They are generally either senior managers, or staff that have been working for

the respective lifeline utilities in a senior technical role. Adults that voluntarily attend WREMO community focus groups that are regularly run on a variety of emergency management subjects will be the community focus group workshop participants.

**Select the type of data collection. \***

Interviews (digitally recorded)

Workshops (digitally recorded)

**Describe the location and anticipated duration of the interview, including whether it will be in work time. (If in work time, have you asked permission for this from the employer?)**

The locations of the interviews will vary depending on the office in which the participant works, however, if the interviewee expresses a preference, the interviews can be conducted at a neutral location of the interviewees choosing.

As the interviewees of the utility organisations are generally senior managers and senior technical staff, it is assumed that the organisations are also happy with their employee's participation in the research. There is therefore not seen to be the need to seek the employer's consent for their senior employees to be involved in the research.

The length of the interviews will be approximately 60 minutes and will be conducted during the daytime but can include early evening (after work hours) if required by the participant.

Community focus group workshops will be conducted in the location in which WREMO normally conducts such workshops, which may be at the WREMO main meeting room, or at a community hall, or similar. It is likely that for this research the community workshops will be conducted out of office hours, either in the early evening or at a weekend.

**Does your project involve sound or image recording? \***

Yes, digital sound.

**Does the project require permission to access databases? \***

The gap analysis modelling will use information provided in 2016 by the lifeline utilities for the purposes of running WeLG/WREMO projects, such as this. While this analysis, to be conducted by the University of Canterbury, may produce satisfactory results, in the case that it does not, the results of the WeLG ‘Programme Business Case’ study (Wellington Lifelines Group, 2019) will be used to compare the PMLOS against, to identify gaps. Either approach would be based on utility data that was provided by the utility organisations for the purpose of such work. Therefore, there are no databases containing any personal information that would be required for this research.

**Does your project involve a non-researcher transcribing the recording? \***

Yes. A transcription non-disclosure-agreement document has been prepared for the purpose, and is attached to this application.

**Will you be providing participants with transcripts of interviews for editing? \***

Yes, for both the interviews, and for the community workshops.

**If your project involves sound or image recording, describe how this will be undertaken and how consent will be given by the participant. \***

An audio recording device will be used during the interviews and community focus group workshops, unless consent is not given by the participant. The participant will be given a consent form to sign, if they wish to decline to the interview being recorded, notes will be taken instead. No image recording will be undertaken.

**What are the possible benefits (if any) of the project to individual participants, groups, communities or organisations? \***

Direct benefits to the participants contributing to this project is that they will be an integral part of improving the understanding of emergency management goals. Furthermore, the research will be beneficial in contributing to the growing understanding of the effectiveness of

emergency management and lifeline utilities' resilience objectives. The resulting PMLOS and gap analysis will also be of use to the utility organisations and the emergency management sector in their organisational and emergency planning.

**Are participants likely to experience discomfort (physical, psychological, social), incapacity or other risk of harm? \***

There is the potential for participants to experience discomfort, if they feel that they are being judged on whether they have previously carried out sufficient emergency management planning. The questions to be posed in the structured interviews are, however, practical in nature, and focussed on the approach of the potential use of PMLOS. There are not any questions that are personally oriented, so the potential for discomfort/distress is considered by the researcher to be not high.

**What discomfort (physical, psychological, social), incapacity or other risk of harm are individual participants likely to experience as a result of participation? \***

For interviews, the main experience that the participant may feel is psychological discomfort due to discussing emergency management for the Wellington region. Most participants understand well their respective roles in emergency management, and therefore in the past have appeared comfortable with discussing both their inputs and the likely performances of their respective organisations in an emergency event. Most will therefore be comfortable discussing the topics in this research. If any participants are found to be displaying signs of discomfort at discussing this subject, the option will be given to cease the interview, or remove any recording that was made in the interview carried out to that point. As the researcher works with the interviews on a regular basis, it is understood that these people have existing avenues for workplace support, where needed, for example if there is a previous distressing event that they wish to talk about. The researcher can remind them of those options, if considered necessary.

For community focus group workshops, the concept of PMLOS will be discussed, with potential 'outage maps' showing how long after a disaster event (such as a rupture of the Wellington Fault) it will be until lifeline utility services will be restored. Outage times of infrastructure following a rupture of the Wellington Fault are already publicly available (Wellington Lifelines Group, 2019), and with the community focus group selected by WREMO

to discuss emergency management issues, the likelihood of stress is relatively low, however, as for interviews, if any participants are found to be displaying signs of discomfort at discussing this subject, the option will be given to cease the workshop, or remove any recording that was made in the interview carried out to that point.

**Describe the strategies you will use to deal with any of the situations identified above? \***

The interviewer, Richard Mowll will be vigilant to any changes to the participant and will offer to terminate the interview if the participant becomes distressed. If any participants are found to be displaying signs of discomfort at discussing this subject, the option will be given to cease the interview, or remove any recording that was made in the interview carried out to that point.

**Is there risk of harm to the researcher, undertaking this project? \***

There is reputational risk to the researcher, in the event that interviews do not go well. This risk is minimised in that the researcher has worked in his WeLG/WREMO capacity since 2011 and has successfully completed projects with the interviewees over this period. Further, the information to be provided prior to the interviews will set the boundaries for the anticipated discussions and point towards the intended interview and project outputs. This should help keep the boundaries of the interviews on their intended topics.

**Is discomfort (physical, psychological, social), incapacity or other risk of harm likely to be experienced by groups/communities or institutions as a result of this research? \***

No physical, psychological or social harm is expected to be suffered by the utility organisations as a result of this research.

Similarly, as the WREMO community focus group is regularly convened to voluntarily discuss emergency preparedness and response issues, it is expected that the potential for discomfort (physical, psychological or social) is low.

**Is ethnicity data being collected as part of this project? \***

No

**Describe how the data and subsequent analysis will be used. \***

The interview and workshop recordings will be transcribed and coded, using the NVIVO software package. A coding analysis will then be performed to establish themes on the use of PMLOS as a concept, and on any new or suggestions on adjusted PMLOS put forward during the interview or workshop(s).

All recordings taken will ‘anonymise’ the interviewees and workshop participants, in that codes will be assigned to the individuals or workshop, meaning that their identify cannot be identified from the name of the recording or file.

The outputs of the research are intended to be a framework of PMLOS. For this, it is likely that, for example, water professionals will have opinions of water PMLOS, electricity professionals will have opinions on power (electricity) PMLOS, etc. Despite this, in all cases, there will be more than one interviewee per subject – i.e. more than one water professional, electricity professional etc. for each type of utility. Therefore, it will not be evident from the research outputs as to which comments would be taken from which person. There may, however, be perceptions that particular individuals could have provided specific suggestions on specifics of the framework. This is a factor of working in the emergency management and ‘resilient infrastructure’ sector. The researcher’s experience of working in this sector since 2011 is that this is common practice, and that those to be interviewed will be used to having their opinions reflected in documents and reports that do not assign comments to individuals but do combine comments sometimes a limited number of sources that produce, largely, factual reports.

In addition to the above, the pre-interview information will make note that there is potential for comments to be assumed to have come from individuals. The interviewees will be given the opportunity not to participate in interviews, and amend transcripts, if they wish to.

**If participants are children / students in a pre-school / school / tertiary setting, describe arrangements you will make for children / students who are present but not taking part in the research. \***

N/A

**Who will give information about the research to potential participants? \***

The lead researcher, Richard Mowll.

**How will the information be given to potential participants \***

A copy of the information sheet and consent form will be sent via email.

**How will consent be obtained? \***

Written

**Are any participants under the age of 16? \***

No

If participants include persons whose capacity to give informed consent may be compromised, describe the consent process that will be used.

The research does not include people who do not have the capacity to provide informed consent.

**Will the participants be proficient in English? \***

Yes

**List any information that will be obtained from any sources other than the participant.**

Apart from the literature review, no information on PMLOS will be obtained from sources other than the participants. The modelling for the gap analysis will, however, be gained from the outputs that the University of Canterbury will work on. That modelling will be carried out using data that the utility organisations will have provided (as detailed above).

**Identify any information that may be given to any person outside the research team that may describe participants.**

No information that may identify individual participants will be given to persons outside of the research team. However, in writing up the results of the research, it will be clear that interviewees are those that work in emergency management, with lifeline utilities in the Wellington region and with key stakeholders to WREMO. If any quotes are used in any research output, including journal articles, they will be anonymised so that they cannot be ascribed back to any particular person.

**Will participants identities' be known to the researchers? \***

Yes

**How will the identities be confidentially maintained in the treatment and use of data? \***

The researchers will not discuss names or any additional identifying information (physical appearance etc) with anyone. Within the write up of the analysis and evaluation, publications or conferences, no original names will be disclosed, however names of individual organisations will be used throughout any discussions or writings. If a particular story or experience is discussed that may identify a participant, the researchers will ask the participant if they would give consent for that particular information to be used in the research.

Further, drafts of any proposed journal articles or publications will be circulated amongst the key stakeholders for checking prior to publication. If any stakeholder (interviewee) objects, the material will be modified until the participant is happy with the material for publication.

**If an institution (e.g. school) to which participants belong is able to be identified, explain how you have made the institution aware of this.**

The contacts at the relevant institutions (lifeline utilities organisations, emergency management organisations, central governmental organisations, non-governmental organisations) are generally higher-level management staff at their respective organisations. It is being taken as read that those staff are communicating their involvement in this research (and project) back into their own organisations (as they have consistently done over past interactions involving Richard Mowll and his work at WREMO since 2011). The above staff members are already aware of this project through consultation on the creation of the WREMO Group Plan (which includes this project). Additionally, interviewees will receive the information sheet for this research prior to interviews. In all previous cases that the researcher has worked with these individuals, they have reported back to their respective organisations appropriately.

**Outline how and where data will be stored, particularly identifiable data. \***

Notes, audio files and interview transcripts will be stored on a password protected computer. Any transcripts or paper forms of the interview notes and consent forms will be locked securely at Massey University.

**Outline how and where consent forms will be stored**

Consent forms will be filed in a separate locked filing cabinet.

**Outline who has access to data and consent forms. \***

Professor David Johnston, Richard Mowll, Dr Julia Becker and Assoc Professor Carol Stewart.

**How will the data / consent forms be protected from unauthorised access? \***

All forms and papers will be securely locked away in a filing cabinet at Massey University.

**How long will the data be kept? \***

5 years

**Who will be responsible for its safekeeping and eventual disposal? \***

Professor David Johnston.

**Will the data be transferred to an official archive? \***

No

**Describe how the Treaty of Waitangi, with reference to the principles of partnership, participation and protection, has been considered and how your research affects Māori.**

\*

This research aims to incorporate the three principles of the Treaty of Waitangi, partnership, participation and protection by speaking with Māori communities and ensuring their experiences and voices are documented. Māori culture is an integral part of New Zealand, thus including Māori in this research is important.

**Are Māori the primary focus of this project, or is it more than likely that participants are Māori (and ethnicity is being collected)? \***

Māori are not the primary focus of this research. It is planned that one interviewee will be from the Greater Wellington Regional Council (GWRC) iwi engagement team. This person is the Iwi representative at GWRC, and his guidance will be taken regarding additional interviewees or workshop/hui attendees. Since around 2019, this person has taken a pivotal role in emergency planning and response, and is trustworthy in making appropriate connections, where required, with Iwi and marae.

**If your research involves the general population, outline how the involvement of Māori participants will be managed. \***

Although Māori are not the primary focus of this research project, Māori participants will be invited to participate in the workshops/hui to share voices and experiences and add to the diverse understandings of PMLOS for Wellington. Such invitations will be put through the GWRC Iwi engagement officer.

**Is the research topic relevant to Māori communities? \***

Yes

**Identify the group/s with whom consultation has taken place, describe the consultation process, and how issues raised in the consultation process have been dealt with.**

The WREMO project was included as an element of the Wellington region emergency management Group Plan (Wellington Region Emergency Management Office, 2019). As such, engagement with the key stakeholders, the general public and iwi has been carried out on the potential for this project to be conducted.

In addition to the above, a discussion with the GWRC iwi engagement officer will be held to ensure that Māori voices are included appropriately in this research.

**Describe any ongoing involvement of the individuals or group/s consulted throughout the project \***

Once engagement with Māori has been established, the relationship will be ongoing for the duration of the research and if requested, we will attend hui to provide a detailed overview of the research findings. For engagement with all other stakeholders, they will be included in the continuing process of work, as for all WREMO projects and activities. This will include at ongoing WeLG meetings, which typically are held two or three times per year. In addition, there are occasional meetings with the utility organisations (either individually or collectively) on resilient infrastructure and emergency management issues, and the PMLOS and progress on the gap analysis work may be discussed, at some level, during such discussions.

**Describe how project findings will be disseminated to the group/s consulted \***

When the project is completed, it is likely that a workshop will be organised to share the results with the relevant staff at WREMO and the key stakeholders. There will be consultation with key stakeholders prior to the publication of any material created as a result of this research. Any proposed journal article will be circulated to the utility organisations for comment, prior to publication. Any conferences or presentations will rest on the information produced in those journal articles, however, should any additional information be potentially presented, the relevant utility organisation(s) will be approached for their agreement for the use of such information.

**Does your research focus on any ethnic or social groups (Other than Māori)? \***

No

**Describe how information resulting from the project will be shared with participants and disseminated in other forums.**

Transcripts will be returned to participants for review and consent for the release of transcripts, prior to further use of those transcripts. The data gathered will be used to evaluate the potential for greater use of PMLOS planning in the Wellington region. Research outcomes may also be published in open access journals so that they are freely available to both local and international audiences, including non-academics.

## **Appendix 3: Information sheet: interviews**

### **Infrastructure planning minimum levels of service for the Wellington region**

#### **Research Information Sheet: September 2021**

Who are we?

Richard Mowll is a PhD researcher at the Joint Centre for Disaster Research at Massey University who has a background in civil engineering, emergency management and infrastructure resilience. Richard is also the Project Manager of the Wellington Lifelines Group (WeLG) and the Lifeline Utilities Co-ordinator with the Wellington Region Emergency Management Office (WREMO). He is conducting research as a PhD student, with acknowledgement of each of the roles he holds. The wider research team for this project comprises of supervisory staff from Massey University, including Dr Julia Becker, Professor David Johnston, and Associate Professor Carol Stewart, and Liam Wotherspoon from the University of Auckland.

Contact details:

Richard Mowll

Tel: +64-21-268-1759

Email: [richard@mowll.nz](mailto:richard@mowll.nz)

If you have any questions, or at any point need to speak with any of the researchers, please do not hesitate to make contact using the above contact details.

What is this research about?

A 'level of service' is a measure of infrastructure, described by asset condition, performance and other relevant outputs (Edwards, 2010). Specific to an emergency situation, we are investigating whether 'planning minimum levels of service' (PMLOS) could be created. One existing example of a PMLOS in the Wellington region is Wellington Water's '20 litres of water, per person, per day, within 1km of the dwelling' (Wellington Water, 2018b). Apart from

Wellington Water's example, there appear to be very few other examples, either locally or internationally, of PMLOS.

This research, which is also a WeLG/WREMO project, aims to create a framework of PMLOS relevant to the Wellington region, and then outline whether those PMLOS may be deliverable with existing infrastructure, mapped at suburb level. For this, past vulnerability assessments may be used to provide assessments of outage times from specific hazards.

By undertaking interviews with the lifeline utilities and key stakeholders in the Wellington region, plus engagement with a local WREMO community focus group through a two-hour workshop, the research seeks to understand: what is needed to develop a framework, relevant to the Wellington region, to define and order emergency levels of service, that would allow interpretation by key stakeholders. Further, what 'planning minimum levels of service' for each infrastructure sector could be defined, relevant to the Wellington region?

The findings from this research will inform the work programme and outputs of the Wellington Lifelines Group.

What will this research involve?

We would welcome the opportunity to interview you about your experiences and insights regarding PMLOS. We expect that the interview will take about 1 hour. If you agree to take part, your involvement will remain confidential, although it will be apparent, for example, that transport participants are most likely to discuss transport issues, energy people will discuss energy issues, etc.

The themes and questions that we will ask you to reflect on during the conversation include the following:

From a research perspective:

- Is the concept of 'planning minimum emergency levels of service' useful for your thinking of resilience?
- Are you aware of any lifeline utilities' response and recovery frameworks (please provide details, if available) that have timebound and measurable levels of service?
- How do you currently assess your organisation's post-event levels of service?

- What hazard events do you use to analyse/identify post-event levels of service (i.e. storm, earthquake, tsunami etc.)?
- A literature review and a paper on a 'preliminary framework' (as produced from literature by WREMO practitioners) are attached to this information sheet. At the interview some mock-ups of where PMLOS can be achieved will be presented.
- Do you see value in creating a response and recovery framework showing whether emergency levels of service can be achieved in particular suburbs?
- Would your organisation participate in the creation / adoption of a framework?
- Is there any reason to not use the Sphere Handbook (Sphere Association, 2018) for water standards, and for guidance of aspects of food, sanitation and shelter?
- For the proposed framework, specific details of nominated timeframes and specific PMLOS will be discussed.

From a WeLG/WREMO perspective:

- Would your organisation support the use of this framework 'for measurement / comparison purposes only'?
- Would your organisation support the use of this framework 'planning minimum levels of service' for emergency planning purposes?
- Do you have any objections to the operationalised framework being published by WeLG and in an academic journal?
- Any other thoughts / comments?

With your consent the interview will be digitally recorded so that the information can be checked and clarified later. After your interview, you will be given the opportunity to review your interview transcript. This will give you a chance to read through your interview, ensure the interviewers have accurately captured what you said, delete or add any information and overall to make sure you are happy with including what you discussed in the interview for research purposes. Once you are happy with the transcript, you will be asked to sign a release of transcript form that gives the researchers consent to use your interview data for the evaluation.

What will the information be used for?

We will analyse the interview data using thematic analysis. This is a common method used to analyse qualitative data in social science research.

Recordings and notes taken during the interview, including names, will be kept confidential by using pseudonyms (a different name). At no point during the research process or typing up of the evaluation will names be disclosed. All recordings and notes taken during the interview will be kept secured and locked away in a filing cabinet at Massey University. You can request to view and edit the information you give us at any time up until it is published.

We intend to publish this research in a peer-reviewed journal, where it will contribute towards enhancing WeLG's, WREMO's and Massey University's understanding of best practice approaches for the creation of PMLOS.

Do I have to take part?

You are under no obligation to accept this invitation. If you decide to participate, you have the right to:

- decline to answer any particular question;
- withdraw from the study (by 30 December 2021, before final write-up occurs);
- ask any questions about the study at any time during participation;
- provide information on the understanding that your name will not be used unless you give permission to the researcher;
- be given access to a summary of the project findings when it is concluded;
- ask for the recorder to be turned off at any time during the interview.

Please ask us if you would like any further information.

This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A, Application 21/40. If you have any concerns about the conduct of this research, please contact Dr Negar Partow, Chair, Massey University Human Ethics Committee: Southern A, telephone 04 801 5799 x 63363, email [humanethicsoutha@massey.ac.nz](mailto:humanethicsoutha@massey.ac.nz)

## **REFERENCES:**

## Appendix 4: Participant consent forms: interviews

### Infrastructure planning minimum levels of service for the Wellington region

#### PARTICIPANT CONSENT FORM (interviews)

I have read the information sheet and have had the details of the research explained to me. My questions have been answered to my satisfaction, and I understand that I can ask further questions at any time.

Yes                      No

I agree to being sound recorded during the interview /  
workshop

I agree to notes being taken during the interview

I wish to have the interview recording and notes  
returned to me

I agree to participate in this study under the  
conditions set out in the information sheet

I confirm that my organisation is aware of, and has  
Approved, my participation in this research to develop a  
Planning Minimum Level of Service framework relevant  
to the lifeline utilities in the Wellington region

Signature: ..... Date: .....

Full name – printed: .....

## Appendix 5: Structured interviews: questions

### From Richard Mowll, researcher:

- Is the concept of ‘planning minimum emergency levels of service’ useful for your thinking of resilience?
- Are you aware of any utilities’ services response and recovery frameworks (please provide details, if available)?
- How do you currently assess your organisation’s post-event levels of service?
- What hazard events do you use to analyse/identify post-event levels of service (i.e. storm, earthquake, tsunami etc.)?
  - Why choose those ones, and do you know what their anticipated outcomes are, regarding your infrastructure?
  - Would the planning minimum emergency levels of service your organisation identified differ, according to hazard (i.e. different post-event LOS for earthquake or storm)?
- Here is the ‘theoretical framework’, as produced from literature and from WREMO practitioners, and some mock-up outputs...
- Do you see value in creating a response and recovery framework showing whether emergency levels of service can be achieved in particular suburbs?
  - If so, why?
  - If not, why not?
- Would your organisation participate in the creation / adoption of a framework?
  - If yes, why?
  - If not, why not?
- Is there any reason to not use the Sphere Standards for water standards, and for guidance of aspects of food, sanitation and shelter?
- For the proposed framework:
  - Are the timeframes of 0-7, 8-30, 31-90 and 90+ days appropriate for the Wellington region?
  - Are there any utilities services that are either missed or that should not be in the framework (i.e. should shelter be in the framework)?
  - Thoughts on the contents of the cells of the framework... comments...

- Are the progression towards higher levels of service appropriate?
- Are the levels of service appropriate – test the progression of each.
- As a holistic set, do these recommendations work together?

**From Richard Mowll, Project Manager of the Wellington Lifelines Group:**

- Do you have any objections to the operationalised framework being published by WeLG and in an academic journal?
- Do you have any objections to the LOS in the framework being compared against likely response and recovery times in suburbs (a mapping)?
- Any other thoughts / comments?

## **Appendix 6: Information sheet: workshops**

### **Infrastructure planning emergency levels of service for the Wellington region**

Research Information Sheet: November 2021

Who are we?

Richard Mowll is a PhD researcher at the Joint Centre for Disaster Research at Massey University who has a background in civil engineering, emergency management and infrastructure resilience. Richard is also the Project Manager of the Wellington Lifelines Group (WeLG) and the Lifeline Utilities Co-ordinator with the Wellington Region Emergency Management Office (WREMO). He is conducting research as a PhD student, with acknowledgement of each of the roles he holds. The wider research team for this project comprises of supervisory staff from Massey University, including Dr Julia Becker, Professor David Johnston, and Associate Professor Carol Stewart, and Liam Wotherspoon from the University of Auckland.

Contact details:

Richard Mowll

Tel: +64-21-268-1759

Email: richard@mowll.nz

If you have any questions, or at any point need to speak with any of the researchers, please do not hesitate to make contact using the above contact details.

What is this research about?

A 'level of service' is a measure of infrastructure, described by asset condition, performance and other relevant outputs (Edwards, 2010). Specific to an emergency situation, we are investigating whether 'planning emergency levels of service' (PELOS) could be created. One existing example of a PELOS in the Wellington region is Wellington Water's '20 litres of water, per person, per day, within 1km of the dwelling' (Wellington Water, 2018). Apart from

Wellington Water's example, there appear to be very few other examples, either locally or internationally, of PELOS.

This research, which is also a WeLG/WREMO project, aims to create a framework of PELOS relevant to the Wellington region, and then outline whether those PELOS may be deliverable with existing infrastructure, mapped at suburb level. For this, past vulnerability assessments may be used to provide assessments of outage times from specific hazards.

By undertaking interviews with the lifeline utilities and key stakeholders in the Wellington region, plus engagement with local community focus groups, the research seeks to understand: what is needed to develop a framework, relevant to the Wellington region, to define and order emergency levels of service, that would allow interpretation by key stakeholders. Further, what 'planning emergency levels of service' for each infrastructure sector could be defined, relevant to the Wellington region?

The findings from this research will inform the work programme and outputs of the Wellington Lifelines Group.

What will this research involve?

We would welcome the opportunity to include you in a workshop regarding insights you may be able to provide regarding PELOS. We expect that the workshop will take about 1 hour. If you agree to take part, your involvement will remain confidential.

The themes and questions that we will ask you to reflect on during the conversation include the following:

From a research perspective:

- Are example levels of service provided at the workshop understandable? Why? Why not?
- Would the example framework help you plan for a disaster? If yes, how? If no, why not?
- How much would it be reasonable for community members to carry back from the supermarket (i.e. 5kg, 10kg, 15kg, 20kg, more)?
- For the 0-7 days services, if community members had the relevant supplies 'in their cupboards', could they survive on these levels of service? What is missing?

- For the 8-30 days services, could community members survive on these levels of service? Discuss.
- For the 31-90 days services, is there anything missing, or any services not listed?
- If you saw this framework again, but showing which of these services currently can, and cannot, be delivered to individual suburbs, would that help community members plan for an event, or inform expectations of a response and recovery?
- Any other comments?

With your consent the workshop will be digitally recorded so that the information can be checked and clarified later. After your interview, you will be given the opportunity to review the workshop transcript. This will give you a chance to read through your workshop, ensure the interviewers have accurately captured what you said, delete or add any information and overall to make sure you are happy with including what you discussed in the workshop for research purposes. You will be asked to sign a release of transcript form that gives the researchers consent to use your interview data for the evaluation.

What will the information be used for?

We will analyse the workshop data using thematic analysis. This is a common method used to analyse qualitative data in social science research.

Recordings and notes taken during the workshop, including names, will be kept confidential by using pseudonyms (a different name). At no point during the research process or typing up of the evaluation will names be disclosed. All recordings and notes taken during the interview will be kept secured and locked away in a filing cabinet at Massey University. You can request to view and edit the information you give us at any time up until it is published.

We intend to publish this research in a peer-reviewed journal, where it will contribute towards enhancing WeLG's, WREMO's and Massey University's understanding of best practice approaches for the creation of PMLOS.

Do I have to take part?

You are under no obligation to accept this invitation. If you decide to participate, you have the right to:

- decline to answer any particular question;

- withdraw from the study (by 30 June 2022, before final write-up occurs);
- ask any questions about the study at any time during participation;
- provide information on the understanding that your name will not be used unless you give permission to the researcher;
- be given access to a summary of the project findings when it is concluded;
- ask for the recorder to be turned off at any time during the interview/ workshop.

Please ask us if you would like any further information.

This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A, Application 21/40. If you have any concerns about the conduct of this research, please contact Dr Negar Partow, Chair, Massey University Human Ethics Committee: Southern A, telephone 04 801 5799 x 63363, email [humanethicsoutha@massey.ac.nz](mailto:humanethicsoutha@massey.ac.nz)

#### **REFERENCES:**

Edwards, R. (2010). Asset Management in the rail and utilities sectors. Thomas Telford.

Wellington Water. (2018). Three Waters Strategy.

<https://www.wellingtonwater.co.nz/dmsdocument/394>

# Appendix 7: Participant consent forms: workshops

## Infrastructure planning minimum levels of service for the Wellington region

### PARTICIPANT CONSENT FORM (workshops)

I have read the information sheet and have had the details of the research explained to me. My questions have been answered to my satisfaction, and I understand that I can ask further questions at any time.

Yes                      No

I agree to being sound recorded during the workshop

I agree to notes being taken during the workshop

I wish to have the workshop recording and notes  
returned to me

I agree to participate in this study under the  
conditions set out in the information sheet

Signature: ..... Date: .....

Full name – printed: .....

## Appendix 8: Structured workshop agenda

- The agenda for the meeting was:
- Introduction/housekeeping
- Brief background / context (most in the room will be familiar with the PELOS concept), including process taken
- Updated mapping tool (signalling where PELOS probably can/cannot be achieved)
- Proposed updates from the preliminary to the updated/operationalised framework (by sector)
- Key issues:
  - Acceptable to publicly release the framework?
  - Adoption of the PELOS, or used for measurement purposes only?
  - Public release of the mapping tool?
- Next steps.
- Any other issues.

## **Appendix 9: EXEMPLAR CREATION OF A PLANNING EMERGENCY LEVEL OF SERVICE: Creating a post-earthquake sanitation plan for the Wellington region, Aotearoa New Zealand**

The following paper was authored during the period that this thesis was being researched. It provides an exemplar for the creation of a planning emergency level of service. It is therefore included in this thesis, for information. As published in the Australian Journal of Emergency Management .

### **9.1 Authors**

Richard Mowl<sup>1,2</sup>, Carol Stewart<sup>2</sup>, Daniel P Neely<sup>1</sup>, Matthew Brenin<sup>2,3</sup>, Mike Fisher<sup>4</sup>, Nickola Loodin<sup>5</sup>, Steve Hutchison<sup>6</sup>

<sup>1</sup> Wellington Region Emergency Management Office, Wellington, New Zealand.

<sup>2</sup> Massey University, Wellington, New Zealand.

<sup>3</sup> Green Earth Development Ltd, Otaki, New Zealand.

<sup>4</sup> Regional Public Health, Wellington, New Zealand.

<sup>5</sup> Wellington Region Emergency Management Office, Wellington, New Zealand.

<sup>6</sup> Wellington Water, Wellington, New Zealand.

### **9.2 Abstract**

The Wellington region in Aotearoa New Zealand experiences regular earthquakes and is vulnerable to potentially lengthy outages of wastewater and road networks. Recognising this, a collaborative project was conducted between scientists and Wellington's water network management company, emergency management body and regional public health authority to create a coherent emergency sanitation plan for a major wastewater system failure. This work built on a foundation of research and a pilot study previously carried out in the region on emergency sanitation. Workshops with project participants created a plan to provide

communities and responders with clearly defined roles and responsibilities. The result is a plan that acknowledges constraints of provision but enables stakeholders and communities to take preparatory steps for, and respond to, sanitation outage events. The plan includes an important infographic about emergency sanitation options as well as what utility and healthcare organisations will do in the event of the plan’s activation.

### 9.3 Introduction

The Wellington region in New Zealand is crossed by many active faults, making it highly vulnerable to earthquakes (Wellington Region Emergency Management Office, 2019). In the case of a rupture of the Wellington Fault, there would be considerable damage to the wastewater system in the region. Outages to the wastewater collection system could last 3 months and may exceed 2 years (Wellington Lifelines Group, 2019) in the Wellington metropolitan area. This would cover the cities of Porirua, Upper Hutt, Lower Hutt and Wellington (see Figure 12), which in 2022, have a combined population of approximately 440,000.

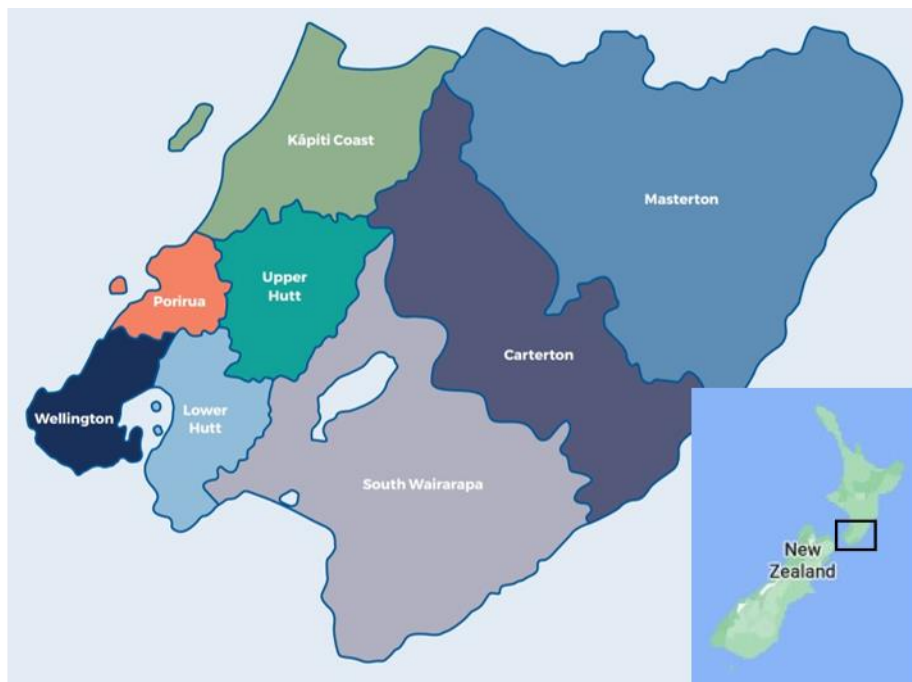


Figure 12: The Wellington region, Aotearoa New Zealand. Source: Wellington Region Emergency Management Office

The Wellington region has a variety of topographies including flat valley floors and hilly suburbs. The steeper topography, in close proximity to some major transport routes, means that

road access around the region could be affected for days to months (Wellington Lifelines Group, 2019). This would reduce the ability of emergency services organisations to respond to the earthquake and would also disrupt services such as refuse collection. While the valley floors are largely away from steeper ground that is exposed to landslides, they are highly vulnerable to liquefaction (Dellow et al., 2018). These factors influence the alternatives for emergency toilets as well as the ability to create a system in which waste (such as from chemical toilets and portable toilets) is collected from dwellings.

The region is host to a variety of living arrangements from timber-framed, stand-alone houses on private land, to multi-storey apartment blocks, particularly in central Wellington City. Further, as for any population, there is a range of ages, capabilities, capacities and ethnicities in the community. This results in differing abilities to cope with and respond to an emergency event, including approaches to sanitation. It also effects people's access to resources, both prior to and during, an emergency event.

#### 9.4 Stakeholder and organisational responsibilities

Local councils of the region carry out the local government functions for the cities. Council-controlled organisations include Wellington Water (for the operation and maintenance of the water, wastewater and stormwater networks for council areas) and the Wellington Region Emergency Management Office (WREMO), which coordinates the Civil Defence and Emergency Management (CDEM) services on behalf of the 9 councils in the region. The councils are responsible for waste management in their areas, although solid waste operations are largely carried out by contractors. Regional Public Health is the public health unit for the greater Wellington region. The work of Regional Public Health includes public health information, working with CDEM and investigating disease outbreaks. Massey University has a campus in Wellington City with staff and students studying in post-earthquake environmental health challenges and solutions.

#### 9.5 Creating an emergency sanitation plan

##### Research and investigations

Recognising the potential for lengthy outages of wastewater and following experiences in the 2011 Christchurch earthquake response, Massey University and WREMO collaborated on a pilot of a 'composting toilet' to capture excreta. This approach uses the concept of separating

the urine and faeces at the source using 2 buckets (now referred to as the ‘two-bucket’ system). This approach means odours are minimised from the waste, the faeces decompose relatively quickly and the bacterial count drops rapidly within 2 months (Brenin, Horswell, et al., 2021).

#### 9.5.1 Stakeholder collaboration and engagement

Massey University led a collaboration with Wellington Water, Regional Public Health, WREMO and the councils understand the process of capture, containment, emptying and transport, treatment and disposal or re-use of excreta, if using the two-bucket system. This led to the councils, WREMO, Wellington Water and Regional Public Health to conduct a project including a wider range of stakeholders to plan for emergency sanitation. Stakeholders were from the local Māori iwi (tribe) (Ngāti Toa) and managers and contractors of solid waste.

#### 9.5.2 Goal of the plan and levels of service

The councils, Wellington Water and WREMO created a high-level goal and target levels of service for an emergency sanitation response:

GOAL:

Minimising gastro outbreaks in the community following an emergency event.

Target levels of service:

- First 7 days - self-sufficiency by the community for sanitation needs. Until the wastewater networks are repaired - residents to dispose of wee and poo on their property.
- From day 8 - if the roads are available and all other systems operational (e.g. fuel supply), options 3 and 4 (as shown in the infographic) will also be viable.

The target levels of service were created to support the outcomes of the plan and to highlight that emergency solutions are not solely for a single organisation to perform. Members of the community will need to be self-sufficient for the first 7 days following an event and adapt their sanitation practices in the weeks and months following until wastewater networks are repaired.

#### 9.5.3 Workshops

Three workshops were conducted for this project. Details of the first workshop held in November 2019 are outlined by Brenin, Stewart, et al. (2021) and covered understanding the process of production, capture, collection and transport, treatment or disposal or re-use of using a sanitation chain framework (Wirmer, 2014). Figure 13 illustrates the sanitation chain. . At this workshop there was also discussion about appropriate terminology and an agreement to avoid euphemisms in public messaging (and for this project), use the terms ‘wee’ and ‘poo’.



Figure 13: The sanitation chain. Source: Wirmer (2014)

The second workshop was in December 2020 and options for emergency sanitation were examined. At this workshop, the options identified at the first workshop were prioritised and a matrix was created (see Table 18). This matrix established the preferred emergency sanitation options that were taken forward and, importantly, excluded some options from further consideration. For example, chemical toilets and community portable toilets were excluded due to the difficulty of collecting and treating the waste after a major earthquake. The elements of the matrix, and each option overall, were graded:

green – for options considered acceptable by most stakeholders and technically feasible

amber - considered acceptable by some participants and/or technical difficulties

red - for options that were technically unfeasible or were considered not acceptable to some stakeholder.

**Table 18: Emergency sanitation options. The emergency sanitation workshops assessed emergency sanitation options as follows:**

Option	Production and capture	Capture/ containment	Collection and transport	Treatment	Disposal or re-use	Overall viability / comments
Long drop	For those where land is suitable and can dig suitable holes (i.e., not on slopes, in liquefaction areas, near drinking water sources, or where there is high ground water.	Acceptable, but messaging on the covering of waste required, to minimise odour and to control vectors (flies).	None	None	None, but messaging / guidance on how to close-out holes would be required (i.e., fill the hole).	Culturally, this is the only acceptable option to Mana Whenua [Māori].  This option is viable, where land is available and where the land conditions allow.
2-bucket toilet	Messaging and socialisation of this concept is required. Otherwise, viable.	Organic additives (sawdust, mulch etc.) will lessen odour and improve the break-down of the solids.	Disposal to green-area land (liquids) and disposal to wheelie-bins/waste bags OR a long-drop (solids).  Assume wheelie-bins are collected in the normal waste-disposal cycle, subject to road access.	Landfill or on-site	Landfill or on-site	Viable, where households have buckets and organic material. Collection by refuse collectors only viable when road access is open.
Bag in a toilet	Requires suitable bags. (Suitable for mobility impaired and apartments. ONLY short-term.)	Suitable, if ONLY poo is in the bag (see emptying and transport).	Transport of poo bags largely viable. Wee bags not viable.	Landfill or on-site	Disposal of poo (in bags) at landfills largely acceptable.	Viable only where wee and poo are separated – i.e., only the bagged poo can be collected in suitable bags.
Bag in a toilet for people with disabilities/aged care	All dynamics are the same, as for ‘bag in a toilet’, however this is considered the only one considered acceptable by the disability sector.	Helper and transfer required in some cases.	At a workshop held on 30 <sup>th</sup> April 2021, it was agreed with the solid waste contractor in attendance that bagged wee, and poo (in one bag) is acceptable in general refuse IF the wee is soaked up with suitable materials such as fine sawdust or gelling agent (Super-Absorbent Material).			Due to access issues this is the ONLY viable option for some people.
Chemical toilet	Requires procurement and delivery, at scale. Ergonomics are not ideal for some users. One per household is desirable, as each house would then take care of/maintain one toilet.	There would be difficulties for some in carrying used (heavy) toilets out to tanks on road. There is a potential for sloppage / spillage. Assistance may be required for some community members.	Challenges of road access for emptying. A fleet of trucks would be required for this operation, at scale. It could suit an outage involving a few suburbs (i.e., not a region-wide outage.)	Concentrated effluent would have to be stored for drip-feeding into treatment plants. (This would not be an issue where treatment ponds are used for treatment – i.e. Wairarapa. DEPENDS ON CHEMICAL USED.)		This option is only viable if: the procurement of the units is viable, transport access between home and treatment plant is possible, the treatment plant is functioning at high capacity and the chemicals used are acceptable.
Community port-a-loo (as a long-term solution)	Unit is outside of house (poor safety). Multiple houses would use one unit, which often leads to units being poorly maintained. There is potential for vandalism. Windy Wellington – ohhhhh!		Challenges of road access for emptying. Fleet of trucks required.	Concentrated effluent would have to be stored for drip-feeding into treatment plant. (Green, where there are ponds).		This option is viable for small-scale (suburb or part of a suburb) short-term outages, so is therefore not considered further in this planning (which is focussed on longer-term outages).

The third workshop was held in April 2021 and identified the emergency sanitation options that would be taken forward for public information. Early drafts of this information were discussed and the final version became the ‘Don’t Flush’ infographic (Figure 14). The workshop focused on 2 objectives:

The end-to-end process from capture to disposal was discussed with managers and solid waste contractors. Options that required the collection and disposal of waste could only be activated if options were operationally feasible. For example, whether it would be acceptable to place bagged human waste into refuse bins and, if so, how this should be done.

The practical and cultural implications for end-users. For example, the option of digging a long-drop toilet (up to 1m deep) in the land at a house appeared, at first consideration, to be a relatively simple task. However, it requires suitable land, digging implements and a suitable seating or crouching arrangement.

This workshop highlighted the need to consider these aspects and the actions to be taken forward in following work. Māori representatives guided the cultural aspects of the plan.

The also workshop highlighted that some people would likely be unable to use a two-bucket solution (e.g. people with weight or mobility issues). Input from disability sector representatives was that limited-mobility people would need to use their regular toilet facilities, which include handrails. Their preferred option would be to use a conventional pedestal toilet, placing a bag within the toilet bowl along with drying material such as sawdust or the super-absorbent material used in nappies. option would be discouraged for the general population because of anticipated difficulties with sourcing of the bags and drying material, disposal of the resulting waste and potential for spillage and mess.

## 9.6 ‘Don’t Flush’

The options for emergency sanitation, as agreed at the third workshop, were translated into an infographic Figure 14 showing the emergency sanitation options. The infographic is a key output of this project as it informs the waste-disposal operators and people in communities about what an emergency sanitation activation entails. It was created to direct people to use options 1 and 2 (disposal on-site) wherever possible and minimise use of options 3 and 4, which require disposal off-site.

# After a large Earthquake Don't Flush!

The pipes that take your wastewater (wees and poos) away could be broken. Listen to the radio or visit [WREMO.nz](http://WREMO.nz) for updates.

For at least 30 days following an earthquake, you'll need to manage your own poos and wees.

## OPTION 1

Do you have an outdoor area where you can dig a hole up to 1m\* deep?

The best solution for you will be to dig a long drop.  
Things you'll need:



Where to dig:



## OPTION 2

Do you have an outdoor area where you can dig a 50cm deep hole?

If you cannot dig deeper than 50cm in your garden you can use the two-bucket system. It is important you keep your wees separate from your poos as it will help keep the smell down and make it safer. Your poos will go in the hole you've dug. Make sure period products go in the bin.

Things you'll need:



Bucket one (wees):

- Add 2-3cm of water to bucket before use
- Don't put toilet paper in this bucket
- Empty daily into an area of your garden or other green space (dilute with water first)



Bucket two (poos):

- Add layer of mulch to bucket before use
- After each use, add a handful of mulch to cover your poos
- Empty every 3 days into the hole you've dug
- Keep dry (reduce smell)
- Menstrual cups should be emptied in this bucket



## OPTION 3

Do you have an outdoor green area where you cannot dig a hole?

You can use the two-bucket system as above, but you'll need to dispose of your poos differently. You'll need to dispose of your poos every 3 days into your outdoor bin.



If none of the above options are physically possible for you

This option should only be used for those with mobility impairments. As a last resort you may place a sturdy plastic bag in your toilet. The bag must be big enough to cover the bowl to avoid spillage. Place some dry material in the bag to soak up your wees and poos. When you need to dispose of the bag, tie the top and put it in your outdoor bin. Make sure you clean your hands thoroughly.



If these options aren't suitable for your needs, you can reach out to your local Community Emergency Hub. Your neighbours might be able to help. Visit [www.getprepared.nz/Hubs](http://www.getprepared.nz/Hubs) to find your local Community Emergency Hub. \*[www.health.govt.nz](http://www.health.govt.nz)



[www.getprepared.nz/Hubs](http://www.getprepared.nz/Hubs)



Figure 14: 'Don't Flush' infographic

## 9.7 Next steps

### 9.7.1 Public education

The third workshop identified that further public information and education must include:

why the options were taken and why some options were not taken

the items that can be purchased pre-event to enable good sanitation practices in an emergency

suggestions on how to build a functional long-drop toilet.

This work will be led by WREMO and will provide reasons why some options were not taken to help address expectations by members of the public that portable toilets and chemical toilets (as provided in Christchurch following the 2011 earthquake) will be provided in Wellington.

### 9.7.2 Procurement and marketing - a public-private partnership

In 2012, WREMO established a public-private partnership to enable people to purchase 200-litre emergency water tanks at an affordable price for \$100 (a saving of \$165). This has generated sales of more than 24,000 water tanks so far (2021) and resulted in nearly 5 million litres of water stored at homes around the region at minimal cost to the ratepayer or taxpayer.

WREMO and Wellington Water worked on a similar approach to improve people's capacity to manage sanitation after an earthquake by promoting the two-bucket approach for toilets. With administrative support from the Greater Wellington Regional Council, a supplier of a two-bucket kit will be supplied as a package comprising two 20-litre buckets with lids, a small seat and 'starter' items including two toilet rolls and disinfectant wipes. WREMO will make this the focus of the annual campaign in 2023 to help people understand how to effectively manage their waste through a range of options from digging a long drop, to using two buckets to modifying their toilet if they have physical challenges.

### 9.7.3 Ongoing engagement

Effective stakeholder engagement was integral to the creating of an emergency sanitation plan for the Wellington region. This engagement will have to continue to progress the public information and education work and to ensure that all parties are prepared to respond in the event of a major failure in the region's water and sanitation systems.

## 9.8 Conclusion

The Wellington region prepares for a major earthquake on the Wellington Fault because of the high-risk of prolonged damage to the region's wastewater collection system. Target levels of service show that households will need to manage their own toilet waste on-site for at least a week. Beyond that time, viable emergency sanitation solutions have been developed that would be viable for households, giving special consideration to people within communities with extra physical or cultural needs. The emergency sanitation plan allows for physical features of the region (ground conditions, topography, likely availability [or not] of roads following a major earthquake) and cultural and social aspects (living arrangements such as house-dwellers and apartment dwellers) and the needs of those who may not be able use long-drop toilets or the two-bucket kits.

The emergency sanitation solutions allow end-users to choose their preferred option, allowing for a range of behaviours, cultures and capacities. This work gives confidence that the options explored were appropriate and achievable for end-users and that a sound process was taken to consider the capture, containment and disposal options for waste.

This progress has identified sanitation options during an emergency for the Wellington region. The next steps will involve informing the region's communities about their options and making two-bucket kits easily available through a public-private partnership.

## **Acknowledgments**

The authors acknowledge QuakeCoRE for their funding for the two-buckets research and appreciate the contribution from the participants in the workshops and throughout the project process.

# Appendix 10: Paper 4, mapping tool – supplementary information

## Workshop UX worksheet and results

### Instruction and Summarised Answer Sheet - WREMO Workshop

Kia ora,

This workshop instruction sheet is designed to help us (Urban Intelligence & the Wellington Regional Emergency Management Office) understand how you engage with and navigate the prototype dashboard.

We will do this by first letting you navigate the interface while following the set of questions below. Please note down any additional comments/issues/questions as you move through the instruction sheet.

At the end of the session, there will be time to verbalise your comments and questions.

Thank you for your participation!

#### Personal Details

Name: (Seven participants)

**Using the laptop in front of you, explore the site for the next 4 minutes before looking at the following page. When the time is up, please minimise the web browser so you can no longer see the original website.**

As you explore the site, note anything you feel about any features of this website that stand out to you (either good or bad)

Good:

- The tutorial at the start was easy to navigate.
- Information display is clear once address has been entered.
- The colour scheme to highlight service levels is good – not sure if accessible for people who are colour blind?

The loading is a bit jumpy.

If I skip tutorial, can I return later? No tutorial button.

Bottom right graph needs title.

Use plain English.

Destination or amenity or service (consistency).

Hours of services not open 24 hrs?

- Wellington CBD (Te Aro) is not in 'Region' drop-down list.
- Social deprivation 1-5 is that high or low deprivation?
- Weekly trips to a water '7' / supermarket '3' / Hub '7' kms?

Looks very high tech! Like the layout.

Not quite clear what socio demographic has to do with 'difficulty walking'.

Also feels like some pre-training is required before you can completely understand what you're looking at.

The graphics are missing the expected number of people who may be accessing each resource during each period, i.e., where would the highest demand / congest queues be?

## 6. How clear is the purpose of the website?

Extremely Unclear	○	1	4	1	1	Extremely Clear
-------------------	---	---	---	---	---	-----------------

What do you believe the purpose of the website is?

Apart from the info box at the start, there's no way to double check what the website is about.

The platform is a database with visual aide to support pre-disaster planning.

To demonstrate outages and distances to walk, number of people affected, time it takes to fix things.

Started thinking it was for anyone – now seems to be for planners – but planning what?

To tell you how long it will take you to get to a supermarket / water station.

Outage times for different services.

Work out the effect on people's access to resources in the event of an emergency. E.g., major earthquake in this instance.

To project the likely amount of resources available at different time periods at a fine scale level.

7. **Regardless of the website's purpose, please answer the questions below about the general usability.**

**How did the website perform?**

Extremely slow	<input type="radio"/>	<input type="radio"/>	2	3	2	Extremely fast/smooth
----------------	-----------------------	-----------------------	---	---	---	-----------------------

**How did you find the navigation and zoomability of the map?**

Extremely hard	<input type="radio"/>	<input type="radio"/>	2	3	2	Extremely easy
----------------	-----------------------	-----------------------	---	---	---	----------------

**Was the text easy to read?**

Extremely hard	<input type="radio"/>	1	2	2	2	Extremely easy
----------------	-----------------------	---	---	---	---	----------------

**If the text was difficult to read, please explain why or how it might be improved**

The colours of the map clash with the text or size of text. It may not be readable on a smartphone?

Bottom right table: vertical writing is not easy to read.

Bit small in places – street names hard to read on background map.

- Shadow on street names not helpful.
- Zoomed in text very hard to read.
- Lots of “distance: undefined km” reference (bit confusing).
- Moving the map is not very smooth; zoom is good.

**Was every feature accessible and appropriately scaled?**

Poorly scaled	○	○	1	2	2	Well scaled
---------------	---	---	---	---	---	-------------

If features or text were not scaled or placed well, please write down any examples

Suburb names and road names. Then suburb disappears as you zoom further in.  
 Location dots not scaling – colour not indicative of purpose – supermarket icon, water drop for water etc.  
 Not sure what all the features are. What are the orange boundaries?  
 Not quite sure what you mean?  
 The zoom function jumped too many levels.

**Were the colours used well contrasted?**

Poorly contrasted	○	1	2	2	2	Well contrasted
-------------------	---	---	---	---	---	-----------------

**Were the colours easy to interpret?**

Extremely hard	1	○	2	3	1	Extremely easy
----------------	---	---	---	---	---	----------------

If anything related to the colours could be improved, please describe below.

Destination colour scheme clashes with the walking distance key/colours.  
 It was easy for my area, but it is simple. Other areas like Karori it was confusing (I realised it later).  
 Light green to dark grey – overlays have hard job – use texture as well, didn't rely on colour – use shapes / icons.  
 A lighter grey would make text stand out more.  
 Approx household weekly walking distance (kms) would add clarity.

Distances in round trips? Is that standard??

Barely visible at bottom left of screen in small font.

(Colours well contrasted for me, but maybe not for colour blindness. Looking at the light blue on dark blue boards.)

Just my point above re colour contrasting

The impact of the colours, their significance, was not clear, except as a contrast between areas.

**8. How well do you understand what each of the amenities/services used within the site are? (e.g. Do you know what an emergency management hub is and what service it may provide after a disaster?)**

**Supermarkets**

Do not understand	○	1	2	○	4	Fully understood
		Hutt City CBD excluded?				

**Water Points**

Do not understand	○	1	2	1	3	Fully understood
			What is it?			

I have been trying to find out where the water points will be for Mt Cook. (I have seen a Newtown map for water points.)

**Emergency Management Hubs**

Do not understand	○	2	2	○	2	Fully understood
-------------------	---	---	---	---	---	------------------

### Health Services

Do not understand	○	1	5	○	1	Fully understood
-------------------	---	---	---	---	---	------------------

(I think there should be difference between hospital vs. GP.)

Waiwhetu disappears.

### Fuel Stations

Do not understand	○	○	○	3	4	Fully understood
-------------------	---	---	---	---	---	------------------

### Power

Do not understand	○	○	3	1	3	Fully understood
-------------------	---	---	---	---	---	------------------

### Telecomms

Do not understand	○	○	3	1	2	Fully understood
-------------------	---	---	---	---	---	------------------

### Broadcast

Do not understand	1	1	3	1	1	Fully understood
-------------------	---	---	---	---	---	------------------

### Sanitation

Do not understand	○	2	3	○	1	Fully understood
-------------------	---	---	---	---	---	------------------

**You may begin using your laptop again.**

**During the next 20-30 minutes please answer the following questions while navigating the website.**

**1. Using ONLY the map, please answer the following questions.**

Please select and write down an address in the WLG region that you are curious about, this could be your home, your work, or any other location significant to you. This address will be used below.

Various...

Other comments placed here:

What can I expect?' button. Label ambiguous.

Search – no autocomplete?

What can I expect? For me, not as intuitive as “my address” (although I got there via the “?”).

How far would a resident at this address have to walk, on average, to a supermarket before a disruptive event?

Correct x 2

Incorrect x 4

How far would a resident at this address have to walk, on average, to a supermarket 8-14 days after an event?

Correct x 1

Incorrect x 5

Summarise in your own words, what is the expected level of service for supermarkets in the WLG region during days 0-7 after a disruption?

Limited access – households will need to be prepared and there will be fewer shops / supermarkets open with limited supply.

Correct x 4

Incorrect x 2

During days 8-14 after a disruption, is the New World in Karori expected to be open or closed?

Closed

Correct x 4

Incorrect x 2

During days 15-30 after a disruption some supermarkets in Lower Hutt are coloured yellow, what does this mean?

Open – servicing priority customers and stock dependent.

Correct x 5

Incorrect x 2

Can the pop-up windows be minimised? I am having to open and close them to see the LoS drop-downs.

Summarise in your own words, what is the expected level of service for power in the WLG region during days 8-14 after a disruption?

Non-functional / Not known = No service / lack of service.

Correct x 7

Incorrect x 0

Summarise in your own words, what is the expected level of service for broadcast in the WLG region during days 8-14 after a disruption?

Partially functional = fully operational for priority radio.

Correct x 6

Incorrect x 1

How many days after a disaster should residents expect to have mobile services returned to normal?

31-90 days.

Correct x 7

Incorrect x 0

### How easy did you find the completion of the previous tasks?

Extremely hard	<input type="radio"/>	1	2	4	<input type="radio"/>	Extremely easy
-------------------	-----------------------	---	---	---	-----------------------	-------------------

What was the most difficult or confusing task to complete and why?

Summarising in my own words what each level of service meant.

I can see that I would need to translate some of this for people where English is a second language.

Mainly because it is a new to me website.

Information is dispersed around the page. Select service, levels of service disruption and key should be tied together somehow.

Rotating between the windows was confusing; but overall not too bad.

Just making sure I read the question correctly 😊!

Actually going through those tasks helped me better understand the dashboard.

It is not clear what the average distance to travel means. It would be helpful to have some idea of the number of trips assumed for supermarket, water, power, sanitation, etc.

### 9. Using any functionality you see fit, please answer the following questions.

In the region of Petone, approximately how many residents could walk less than 4km to a health service during the first 7 days post disaster?

1,500

Correct x 3

Incorrect x 3

The time since disruption radio buttons are inverted – usually \* means on; o means ‘off’.

There must be people with temporarily dodgy knees etc. too.

Is this disability data in the census?

In the region of Newtown, approximately how many residents with a known walking impairment would have to walk over 1km to access a water distribution point during the first 7 days post disaster?

All of them... around 3,400 (isolated)

Correct x 3

Incorrect x 4

**How easy did you find the completion of the previous tasks?**

Extremely hard	<input type="radio"/>	<input type="radio"/>	3	4	<input type="radio"/>	Extremely easy
-------------------	-----------------------	-----------------------	---	---	-----------------------	-------------------

What was the most difficult or confusing task to complete and why?

It wasn't clear on the graph, which data set applied to less than 4km as there were 2 bars 0-2m and 2-4km.

Missed the socio demographic option has options, unsure of its meaning / importance.

5- but mainly because I had social deprivation selected and didn't know.

Maybe have a drop down that summarises the data in words?

Trying to figure out if the graph was answering the question.

The above question.

How to select a region on the map as the dropdown menu, as not all areas and suburbs are in the drop down menu, e.g., Wellington Eastern Suburbs.

**10. Using any functionality you see fit, please answer the following questions.**

If your household was to collect water once per day, visit the supermarket twice per week, and visit an emergency management hub three times per week, how many collective kilometres would the members of your household have to walk during days 8-14?

Correct x 2

Incorrect x 4

Now using '153 Park Road, Miramar, Wellington', how many days should this address be prepared to go without a clean water source?

7 days

Correct x 5

Incorrect x 1

I'm not sure where to type in the address. Sorry I didn't see it before.

Using the same address as above, how many days should this address be prepared to go without food supplies within a 4km round trip to a supermarket?

30 days

Correct x 2

Incorrect x 3

Gosh sorry. I can't find this / don't understand the question.

Using the same address as above, how many days should this address be prepared to go without a flushing toilet?

90+ days

Correct x 5

Incorrect x 1

If you used the 'what can I expect' function, did the programme have any difficulty finding your address? If so, please state your address and the issue arising. If you didn't use this feature, please explain how you got the answer above.

It worked well for addresses above.

However did not work for a flat / unit address e.g. 2/93 Townsend Road, Miramar.

I didn't see the function until I was shown. For my own household I calculated and now I see the distance is much greater.

OK, but predictive seems to be normal, and using <return> to trigger.

As above "your address" is more intuitive to me.

Ohhh – I didn't realise I had to scroll up! Maybe each time you go in should "land" at the top of the page.

## 11. General questions

**As a resident, does the site provide adequate information around how to prepare for a disaster?**

Definitely not	<input type="radio"/>	<input type="radio"/>	2	2	3	Definitely
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What would you do to improve this information or visibility of information?

Including a help function, to prompt planning if you don't remember what the different services mean.

Put in my address – have a report generated with all data and summarised which I can print to work to.

Just make the “What to expect” box more clear. I don’t know how, sorry (other than my previous comments).

Identify what points are and locations.

Indicate the nearest 3 options for a service for a given address.

Final comments:

12. Is there any else you struggled with or found confusing?
13. Is there any additional information you feel relevant to include?
14. Is there anything else you would like to comment on?

- The bar graph of the bottom right hand corner and how that was relative to isolated communities.
- Having a ‘more info’ tab or FAQs or glossary box to help keep in mind what the services mean.
- Wondering how accessible this platform will be for visual impairments? Colour and readability?
- A button to link to the tutorial if I get lost along the way.

1. Navigation, information hidden, connected info in 3/4 corners of screen – cognitive overload. Wording a little tech – plain English – i.e. toilet, mobile phone, SMS, data (are these phased in? Functional?)

2. Complex data – address – report.

Just change “Emergency management Hubs” to Community Emergency Hub.

Maybe sanitation to “toilets / sewage”.

Also “Broadcast” to “internet”.

Common language the community use in every day i.e. emergency management jargon.

Otherwise looks great 😊

- It was not clear on the map whether the distances were one way or round-trip, e.g., for supermarkets, water points, emergency management hubs, health services, and fuel stations.
- It would be helpful to select a set of cells / blocks and get the information for those cells / blocks specifically.

- Present the tool in the emergency management hubs or neighbourhood meetings to groups of residents.