REPORT

Lifelines Consequence Assessment - Guidance

Prepared for
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Executive summary

This guidance report has been developed for Bay of Plenty Regional Council in order to facilitate an assessment of ‘consequence’ for lifelines utilities as part of the risk-based assessment methodology required under the natural hazard provisions of their Regional Policy Statement (RPS).

As shown in Figure A, a simple 4-step process has been developed to facilitate the assessment of lifeline consequences using the RPS methodology, which:

- Estimates the number of people potentially affected by the outage (either >20% or <20% of the population); and
- Estimates a possible outage time (months, weeks, days etc).

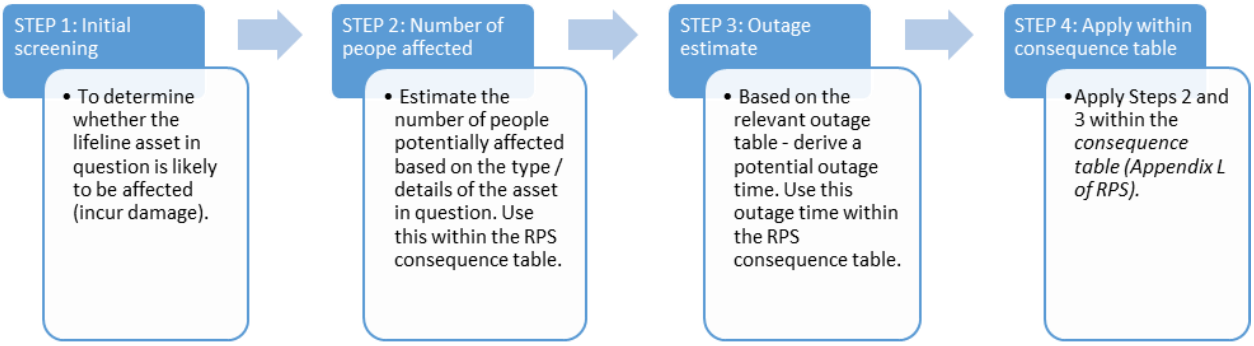

Figure A: Steps to undertake lifelines consequence assessment for RPS

Both of the outputs from steps 2 and 3 can then be used to determine a ‘consequence’ rating within the RPS risk-based methodology (step 4).

This report provides guidance on how to assess potential consequences to lifelines utilities from natural hazards. The guidance is based on a series of look up tables showing the potential outage time of lifeline utilities for a range of hazard magnitudes.

1 Introduction

The focus of this report is to provide a methodology to assess the scale of consequence from natural hazards to lifelines utilities. This assessment can then feed into the **Bay of Plenty Regional Policy Statement (RPS) risk-based approach** (refer BOPRC RPS natural hazard provisions and Appendix L of the RPS) - and in particular, as input information to the consequence table within Appendix L (Figure 1.1). It is noted that this is only one step within the broader RPS risk-based approach which is outlined in detail within Appendix L of the RPS.

This report is intended to be used by practitioners who are required to utilise the risk-based approach within the RPS. These practitioners may include policy planners, consent planners, and consent applicants.

Currently, there is little guidance around undertaking the RPS consequence assessment for lifeline utilities, and as such, there is uncertainty and inconsistency when the prescribed risk-based methodology is applied.

In particular, this report provides guidance on the following, in relation to consequences for lifelines utilities:

1. Estimating the number of people potentially affected by the outage (either >20% or <20% of the population;
2. Estimating a possible outage time (months, weeks, days etc.); and
3. How to then use the above inputs within the consequence table (Figure 1.1).

Consequence level	Built			Lifelines utilities
	Social/cultural	Buildings	Critical buildings	
Catastrophic	≥25% of buildings of social/cultural significance within hazard assessment area have functionality compromised.	≥50% of buildings within hazard assessment area have functionality compromised.	≥25% of critical buildings within hazard assessment area have functionality compromised.	A lifeline utility service is out for > 1 month (affecting ≥ 20% of the town/city population) OR out for > 6 months (affecting < 20% of the town/city population).
Major	11–24% of buildings of social/cultural significance within hazard assessment area have functionality compromised.	21–49% of buildings within hazard assessment area have functionality compromised.	11–24% of critical buildings within hazard assessment area have functionality compromised.	A lifeline utility service is out for 1 week – 1 month (affecting ≥ 20% of the town/city population) OR out for 6 weeks to 6 months (affecting < 20% of the town/city population).
Moderate	6–10% of buildings of social/cultural significance within hazard assessment area have functionality compromised.	11–20% of buildings within hazard assessment area have functionality compromised.	6–10% of critical buildings within hazard assessment area have functionality compromised.	A lifeline utility service is out for 1 day to 1 week (affecting ≥ 20% of the town/city population) OR out for 1 week to 6 weeks (affecting < 20% of the town/city population).
Minor	1–5% of buildings of social/cultural significance within hazard assessment area have functionality compromised.	2–10% of buildings within hazard assessment area have functionality compromised.	1–5% of critical buildings within hazard assessment area have functionality compromised.	A lifeline utility service is out for 2 hours to 1 day (affecting ≥ 20% of the town/city population) OR out for 1 day to 1 week (affecting < 20% of the town/city population).
Insignificant	No buildings of social/cultural significance within hazard assessment area have functionality compromised.	<1% of buildings within hazard assessment area have functionality compromised.	No damage within hazard assessment area, fully functional.	A lifeline utility service is out for up to 2 hours (affecting ≥ 20% of the town/city population) OR out for up to 1 day (affecting < 20% of the town/city population).

Figure 1.1: Consequence table (from RPS, Appendix L)

For the purposes of this assessment, the lifeline utilities which were reviewed included: power; water supply; wastewater; roads; telecommunication; gas.

Four natural hazards were considered: flood; tsunami; volcanic ashfall; liquefaction.

Coastal erosion was deemed to result in permanent outage for the asset (as the land would likely be lost) – and therefore this is catastrophic. Outages due to landslide is dependent on the location, volume, extent and number of landslides, along with the triggering mechanism of the event (e.g.

rainfall or earthquake). Given this complexity, this was not assessed and is an area of further study. Earthquake shaking is outside the RPS requirements and therefore was not included.

Section 2 of this report briefly outlines the methodology used to derive outage times, and population affected.

Section 3 contains a step-by-step process for deriving a consequence rating from the outage times and estimate of population affected.

Sections 4-9 contain detailed outage time ‘look-up’ tables which have been developed.

The Appendices to this report contain more detailed information – including a literature review which supports the outage tables developed.

2 Methodology and assumptions

We conducted an extensive literature review, to document and understand vulnerability functions relating to the relevant assets and natural hazards. We then estimated the expected degree of damage for each asset class, in relation to different hazard magnitudes. It is noted that these hazard magnitudes are a key input to the process and need to be obtained / generated / estimated by the user prior to using this methodology.

We verified the expected damage estimates through interviews with network operators and developed *approximate outage durations* for varying levels of natural hazard event magnitude – presented in the form of simple, high-level, look-up tables - for different asset types, relating to different hazards. Our methodology is further detailed in Appendix A.

It is noted that outage duration for a particular asset is a function of a range of factors, including (but not limited to) the following:

- The degree of damage (which depends on hazard magnitude and asset characteristics)[1];
- The ease of repair (time and resources needed);
- The ease of access to the damaged asset location;
- Outage of interdependent infrastructure (e.g. power, telecommunications, fuel, roading).

Of these four elements, the first two were considered in our assessment and in the development of the outage look-up tables. The ease of access and outage of interdependent infrastructure however, were excluded. *It was assumed, for the purposes of this work, that access is available and other dependant infrastructure is functioning*. If services are reliant on other lifelines, the user should consider assessing those services independently, in order to estimate overall outage duration.

3 Undertaking the consequence assessment as part of the RPS

This section presents four steps which a practitioner can follow in order to estimate both 'number of people affected' and 'outage time' for the purpose of determining the scale of consequence within the RPS Table is shown in Figure 3.1

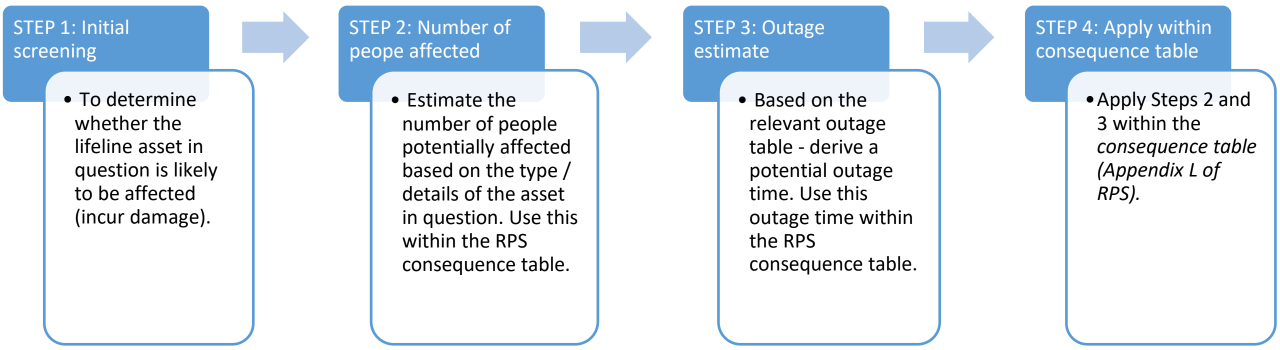

Figure 3.1: Steps to undertake lifelines consequence assessment for RPS

Note there are a range of inputs that are required for Steps 2 and 3. These are discussed in the sections below. A worked example assessment is provided within Appendix C.

[1] This is described by a *vulnerability function* – which describes the degree of damage relative to hazard magnitude.

3.1 Step 1 – Initial screening for damage

This step involves an initial screening assessment relating to whether any material damage will likely be sustained by an asset in relation to a given hazard. This is carried out by referring to

Table 3.1.

For example, a buried power transmission line will be susceptible to damage by liquefaction, however will not likely be susceptible to damage by volcanic ash.

If an asset is deemed to be *affected* (score of 1), then the user proceeds to steps 2, 3 and 4. If the asset is deemed to be *unaffected* (score of 0), then no further assessment is required and the consequence rating from the RPS table (Figure 1.1) is '**insignificant'.**

Table 3.1: Damage potential for different sectors, assets types and hazard

	Flooding	Tsunami	Volcanic ash	Liquefaction
Power				
Power substations	1	1	1	1
Power transmission and distribution (t&d) lines - overhead on poles	1	1	1	1
Power t&d lines - overhead on pylons	1	1	1	1
Power t&d lines - buried	1	1	0	1
Power generation sites	1	1	1	1
Water supply				
Treatment plants	1	1	1	1
Pump stations	1	1	1	1
Reservoirs	0	0	1	1
Pipes	1	1	0	1
Groundwater intakes	1	1	1	1
Surface water intakes	1	1	1	1
Wastewater				
Treatment plants	1	1	1	1
Pump stations	1	1	1	1
Pipes	1	1	1	1
Road transportation				
Roads	1	1	1	1
Telecommunications				
Exchanges	1	1	1	1
Overhead cables	0	1	1	1
Buried cables	1	1	0	1
Roadside cabinets	1	1	1	1
Cell towers	0	1	1	1
Gas				
Pipes	1	1	0	1
Delivery points and valves	1	1	0	1

Key: 1 - Affected | 0 - Unaffected

3.2 Step 2 – Assess number of people affected

This step involves estimating the number of people potentially effected by an outage of the asset in question. This can be undertaken in two ways – either of which are acceptable:

1. By undertaking a case-specific assessment of the local network and providing evidence of the approximate number of people affected by an outage; or
2. Using the look-up table below (Table 3.2). This table has been developed through discussions with various infrastructure operators and is used to inform an indicative idea of the number of people affected, for use within the RPS.

It is noted that if using method 1) above, the percentage relates to the number of people likely affected by the outage, divided by the *total* population of the town or city in which the development is occurring. It is noted that in some cases, an outage may affect a wider area, outside of the town/city boundaries. In this case, it is recommended to use method 2), which is based on asset type.

Table 3.2: Criticality for asset types represented by affected population

Asset type	**< 20% town/city population**	**> 20% town/city population**
Power		
Power substations	-	All substations
Power transmission and distribution lines - overhead on poles	Distribution lines	Transmission lines
Power transmission and distribution lines - buried	Distribution lines	Transmission lines
Power transmission lines - overhead on pylons	-	Transmission lines
Power generation sites	-	All generation sites
Water supply		
Treatment plants	-	All treatment plants
Pump stations	-	All pump stations
Reservoirs	-	All reservoirs
Pipes	Diameter ≤ 100 mm	Diameter > 100 mm
Groundwater intakes	-	All groundwater intakes
Surface water intakes	-	All surface water intakes
Wastewater		
Treatment plants	-	All treatment plants
Pump stations	-	All pump stations
Pipes	Diameter ≤ 150 mm	Diameter > 150 mm
Road transportation		
Roads	Access or collector road (ONRC)	Arterial, regional, or national road (ONRC)

Asset type	< 20% town/citypopulation	> 20% town/city population
Telecommunications		
Exchanges	-	All exchanges
Overhead cables	All overhead cables	-
Buried cables	Network fibre or ≤ 1000 pair distribution	Core fibre or > 1000 pair network
Roadside cabinets	Al roadside cabinets	-
Cell towers	All cell towers	-
Gas		
Pipes	PVC pipes	Steel pipes
Delivery points and valves	-	All delivery points and valves

Once a categorisation of '<20%' or '>20%' of the town/city population has been estimated, then this is used to select the relevant consequence category within the consequence table (Figure 1.1). Refer also to the example within Appendix C.

3.3 Step 3 – Estimate outage time

This step involves assessing outage time based on a range of outage tables which have been developed for each asset type, and each hazard. These tables have been developed through interviews with network operators and research. Refer to Appendix A for further details on the methodology.

An example table for volcanic ash impact on a substation is provided below (Table 3.3). This table indicates that for ash depths of < 3 mm there is likely no outage, and for depths of 3-10 mm, an outage in the order of *days to weeks* could be expected. Similarly, for depths of 10-100 mm, an outage time of *weeks to months* may occur, and finally for depths of more than 100 mm, outage times may be *greater than 6 months*.

Table 3.3: Example outage table for volcanic ash impact on a power substation

	Hours	Days	Weeks	Months	> 6 months
Volcanic Ash (Depth)					
< 3 mm	No impact or disruption expected				
3 - 10 mm					
10 - 100 mm					
> 100 mm					

The following key points are noted, and are important to understand when using these tables.

- A key input for using these tables are local hazard assessments which the user can utilise to understand the relevant hazard magnitude (ash depth, flood depth, tsunami depth, liquefaction classification). This hazard information will also be required more broadly for the RPS assessment (Appendix L) and will need to be appropriately sourced, generated or estimated. The Annual Exceedance Probability (AEP) of the events to be assessed are stipulated within the RPS Appendix L. Refer also to the example presented within Appendix C.
- The outage times are broad estimates only and are intended for use within the RPS process.
- The outage times assume that a **typical** asset is impacted by the hazard and there are no specifically designed mitigation measures in place.

- Outage mitigation measures for the discussed hazards are to be considered as a separate stage within the RPS risk-assessment process.
- It is assumed that access to the asset is available, and interdependent infrastructure is functional.
- For the more catastrophic hazard events (large tsunamis and earthquakes) the outage times are intended to reflect the fact that large numbers of assets may be affected, and therefore resourcing may be limited and outage times exacerbated as a result.

As shown in Table 3.3, the hazard range can cross several outage time scenarios. This represents the variability in the restoration of service time that could occur due to the hazard event and severity, individual asset characteristics or availability of replacement components. The user will need to apply their judgement when selecting an outage duration as part of their assessment. It may be prudent to test the extremes of the outage range (for the given hazard intensity) and the influence this has on the overall RPS risk assessment result.

In the following sections we present the estimated outage durations for the range of assets investigated, and natural hazards considered. The outage duration is directly related to the degree of damage predicted for the range of hazard magnitudes.

Refer to Appendix B for further information on the outage (and damage) based on both literature review and discussions with network operators.

4 Power sector outage

We have assessed outage for the three main asset types within the power sector – namely: substation, power lines (overhead on poles, overhead on pylon and buried) and power generation sites. Each of these are presented below. Refer to Appendix B for further information on the outage (and damage) based on both literature review and discussions with network operators.

4.1 Substation

Refer to Appendix B Section 1.1 for further information on outage and damage.

	Hours	Days	Weeks	Months	> 6 months
Volcanic ash (depth)					
< 3 mm	No impact or disruption expected				
3 - 10 mm					
10 - 100 mm					
> 100 mm					

	Hours	Days	Weeks	Months	> 6 months
Flood (depth)					
< 0.3 m	No impact or disruption expected				
0.3 - 2 m					
> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Tsunami (depth)					
< 0.1 m					
0.1 - 0.5					
0.5 - 2.5 m					
> 2.5 m					

	Hours	Days	Weeks	Months	> 6 months
Liquefaction*					
None to Minor					
Minor to Moderate					
Moderate to Severe					

*Classification based on: *Planning and engineering guidance for potentially liquefaction-prone land* (MBIE, 2017)

4.2 Power lines – overhead on poles

Refer to Appendix B Section 1.2 for further information on outage and damage.

	Hours	Days	Weeks	Months	> 6 months
Volcanic ash (depth)					
< 3 mm	No impact or disruption expected				
3 - 10 mm					
10 - 100 mm					
> 100 mm					

	Hours	Days	Weeks	Months	> 6 months
Flood (depth)					
< 0.3 m	No impact or disruption expected				
0.3 - 2 m					
> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Tsunami (depth)					
< 0.5 m					
0.5 - 3 m					
> 3 m					

	Hours	Days	Weeks	Months	> 6 months
Liquefaction*					
None to Minor					
Minor to Moderate					
Moderate to Severe					

*Classification based on: *Planning and engineering guidance for potentially liquefaction-prone land* (MBIE, 2017)

4.3 Power lines – overhead on pylons

Refer to Appendix B Section 1.3 for further information on outage and damage.

	Hours	Days	Weeks	Months	> 6 months
Volcanic ash (Depth)					
< 3 mm	No impact or disruption expected				
3 - 10 mm					
10 - 100 mm					
> 100 mm					

	Hours	Days	Weeks	Months	> 6 months
Flood (Depth)					
< 0.3 m	No impact or disruption expected				
0.3 - 2 m					
> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Tsunami (Depth)					
< 0.5 m					
0.5 - 3 m					
> 3 m					

	Hours	Days	Weeks	Months	> 6 months
Liquefaction*					
None to Minor					
Minor to Moderate					
Moderate to Severe					

*Classification based on: *Planning and engineering guidance for potentially liquefaction-prone land* (MBIE, 2017)

4.4 Power lines – buried

During discussions with Horizon Energy it was deemed, given the power lines are buried and not exposed, that no damage would likely result from volcanic ashfall. This was based on observations from past events. Therefore, the tables below do not include volcanic ashfall hazard.

Refer to Appendix B Section 1.4 for further information on outage and damage.

	Hours	Days	Weeks	Months	> 6 months
Flood (Depth)					
< 2 m	No impact or disruption expected				
> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Tsunami (Depth)					
< 0.5 m					
0.5 - 3 m					
> 3 m					

	Hours	Days	Weeks	Months	> 6 months
Liquefaction*					
None to Minor					
Minor to Moderate					
Moderate to Severe					

*Classification based on: *Planning and engineering guidance for potentially liquefaction-prone land* (MBIE, 2017)

4.5 Power generation sites

Refer to Appendix B Section 1.5 for further information on outage and damage. While it is acknowledged the different power generation methods (e.g. geothermal and hydropower) each have their own unique vulnerability characteristics, for the purposes of this assessment, the damage to generic power generation site components have been considered when assessing damage and subsequent outage.

	Hours	Days	Weeks	Months	> 6 months
Volcanic Ash (Depth)					
< 3 mm	No impact or disruption expected				
3 - 10 mm					
10 - 100 mm					
> 100 mm					

	Hours	Days	Weeks	Months	> 6 months
Flood (Depth)					
< 0.3 m	No impact or disruption expected				
0.3 - 2 m					
> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Tsunami (Depth)					
< 0.5 m					
0.5 - 1.5 m					
> 1.5 m					

	Hours	Days	Weeks	Months	> 6 months
Liquefaction*					
None to Minor					
Minor to Moderate					
Moderate to Severe					

*Classification based on: *Planning and engineering guidance for potentially liquefaction-prone land* (MBIE, 2017)

5 Water supply sector outage

We have assessed the main asset types within the water supply sector – namely: treatment plant sites, pump stations, reservoirs, pipes and both groundwater and surface intakes. Each of these are presented below. Refer to Appendix B for further information on the outage (and damage) based on both literature review and discussions with network operators.

5.1 Water treatment plants

Refer to Appendix B Section 2.1 for further information on outage and damage.

	Hours	Days	Weeks	Months	> 6 months
Volcanic ash (Depth)					
< 3 mm	No impact or disruption expected				
3 - 20 mm					
20 - 100 mm					
> 100 mm					

	Hours	Days	Weeks	Months	> 6 months
Flood (Depth)					
< 0.5 m					
0.5 - 2 m					
> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Tsunami (Depth)					
< 0.5 m					
0.5 - 2 m					
> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Liquefaction*					
None to Minor					
Minor to Moderate					
Moderate to Severe					

*Classification based on: *Planning and engineering guidance for potentially liquefaction-prone land* (MBIE, 2017)

5.2 Pump stations

Refer to Appendix B Section 2.2 for further information on outage and damage.

	Hours	Days	Weeks	Months	> 6 months
Volcanic Ash (Depth)					
< 5 mm	No impact or disruption expected				
> 5 mm					

	Hours	Days	Weeks	Months	> 6 months
Flood (Depth)					
< 0.5 m					
0.5 - 2 m					
> 2 m					

	hours	Hours	Days	Weeks	Months
Tsunami (Depth)					
< 0.5 m					
0.5 - 2 m					
> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Liquefaction*					
None to Minor					
Minor to Moderate					
Moderate to Severe					

*Classification based on: *Planning and engineering guidance for potentially liquefaction-prone land* (MBIE, 2017)

5.3 Reservoir

During discussions with Tauranga City Council (TCC) staff it was deemed, given the water reservoirs are typically tanks on elevated ground, that no damage would likely result from a flood or tsunami. This was based on observations from past events. Therefore, the tables below do not include flood and tsunami hazard.

Refer to Appendix B Section 2.3 for further information on outage and damage.

	Hours	Days	Weeks	Months	> 6 months
Volcanic ash (Depth)					
< 100 mm	No impact or disruption expected				
> 100 mm					

	Hours	Days	Weeks	Months	> 6 months
Liquefaction*					
None to Minor					
Minor to Moderate					
Moderate to Severe					

*Classification based on: *Planning and engineering guidance for potentially liquefaction-prone land* (MBIE, 2017)

5.4 Pipes

During discussions with TCC it was deemed, given the water supply pipes are buried closed systems and not exposed, that no damage would likely result from volcanic ashfall. This was based on observations from past events. Therefore, the tables below do not include volcanic ashfall hazard.

Refer to Appendix B Section 2.4 for further information on outage and damage.

	Hours	Days	Weeks	Months	> 6 months
Flood (Depth)					
< 0.5 m	No impact or disruption expected				
0.5 - 2 m		■			
> 2 m		■	■		

	Hours	Days	Weeks	Months	> 6 months
Tsunami (Depth)					
< 0.5 m	No impact or disruption expected				
0.5 - 2 m		■	■		
> 2 m			■	■	

	Hours	Days	Weeks	Months	> 6 months
Liquefaction*					
None to Minor			■		
Minor to Moderate				■	
Moderate to Severe				■	■

*Classification based on: *Planning and engineering guidance for potentially liquefaction-prone land* (MBIE, 2017)

5.5 Groundwater intakes

Refer to Appendix B Section 2.5 for further information on outage and damage.

	Hours	Days	Weeks	Months	> 6 months
Volcanic ash (Depth)					
< 5 mm	No impact or disruption expected				
5 - 20 mm		■	■		
20 -100 mm			■	■	
> 100 mm				■	■

	Hours	Days	Weeks	Months	> 6 months
Flood (Depth)					
< 0.5 m		■	■		
0.5 - 2 m			■		
> 2 m			■	■	

	Hours	Days	Weeks	Months	> 6 months
Tsunami (Depth)					
< 0.5 m					
0.5 - 2 m					
> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Liquefaction*					
None to Minor					
Minor to Moderate					
Moderate to Severe					

*Classification based on: *Planning and engineering guidance for potentially liquefaction-prone land* (MBIE, 2017)

5.6 Surface water intakes

Refer to Appendix B Section 2.6 for further information on outage and damage.

	Hours	Days	Weeks	Months	> 6 months
Volcanic ash (Depth)					
< 5 mm	No impact or disruption expected				
5 - 20 mm					
20 -100 mm					
> 100 mm					

	Hours	Days	Weeks	Months	> 6 months
Flood (Depth)					
< 0.5 m					
0.5 - 2 m					
> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Tsunami (Depth)					
< 0.5 m					
0.5 - 2 m					
2> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Liquefaction*					
None to Minor					
Minor to Moderate					
Moderate to Severe					

*Classification based on: *Planning and engineering guidance for potentially liquefaction-prone land* (MBIE, 2017)

6 Wastewater sector outage

We have assessed three main asset types within the wastewater sector – namely: treatment plants, pump stations and pipes. Each of these are presented below. Refer Appendix B for further information on the outage (and damage) based on both literature review and discussions with network operators.

6.1 Treatment plants

Refer to Appendix B Section 3.1 for further information on outage and damage.

	Hours	Days	Weeks	Months	> 6 months
Volcanic ash (Depth)					
< 3 mm	No impact or disruption expected				
3 - 10 mm					
10 - 50 mm					
> 50 mm					

	Hours	Days	Weeks	Months	> 6 months
Flood (Depth)					
< 0.5 m					
0.5 - 2 m					
> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Tsunami (Depth)					
< 0.5 m					
0.5 - 2 m					
> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Liquefaction*					
None to Minor					
Minor to Moderate					
Moderate to Severe					

*Classification based on: *Planning and engineering guidance for potentially liquefaction-prone land* (MBIE, 2017)

6.2 Pump stations

Refer to Appendix B Section 3.2 for further information on outage and damage.

	Hours	Days	Weeks	Months	> 6 months
Volcanic ash (Depth)					
< 5 mm	No impact or disruption expected				
5 - 20 mm					
20 - 100 mm					
> 100 mm					

	Hours	Days	Weeks	Months	> 6 months
Flood (Depth)					
< 0.5 m					
0.5 - 2 m					
> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Tsunami (Depth)					
< 0.5 m					
0.5 - 2 m					
> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Liquefaction*					
None to Minor					
Minor to Moderate					
Moderate to Severe					

*Classification based on: *Planning and engineering guidance for potentially liquefaction-prone land* (MBIE, 2017)

6.3 Pipes

Refer to Appendix B Section 3.3 for further information on outage and damage.

	Hours	Days	Weeks	Months	> 6 months
Volcanic ash (Depth)					
< 10 mm	No impact or disruption expected				
10 -50 mm					
50 - 250 mm					
> 250 mm					

	Hours	Days	Weeks	Months	> 6 months
Flood (Depth)					
< 0.5 m	No impact or disruption expected				
0.5 - 2 m					
> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Tsunami (Depth)					
< 0.5 m	No impact or disruption expected				
0.5 - 2 m					
> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Liquefaction*					
None to Minor					
Minor to Moderate					
Moderate to Severe					

*Classification based on: *Planning and engineering guidance for potentially liquefaction-prone land* (MBIE, 2017)

7 Road transportation outage

This section presents outage tables for roads. Refer Appendix B for further information on the outage (and damage) based on both literature review and discussions with network operators.

7.1 Roads

Refer to Appendix B Section 4 for further information on outage and damage.

	Hours	Days	Weeks	Months	> 6 months
Volcanic ash (Depth)					
< 2 mm	No impact or disruption expected				
2 - 50 mm					
50 - 150 mm					
> 150 mm					

	Hours	Days	Weeks	Months	> 6 months
Flood (Depth)					
< 0.5 m					
0.5 - 2 m					
> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Tsunami (Depth)					
< 0.5 m					
0.5 - 2 m					
> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Liquefaction*					
None to Minor	No impact or disruption expected				
Minor to Moderate					
Moderate to Severe					

*Classification based on: *Planning and engineering guidance for potentially liquefaction-prone land* (MBIE, 2017)

8 Telecommunications outage

This section presents outage tables for four main asset types within the telecommunications sector – namely: exchange buildings, overhead cables, buried cables and roadside cabinets. Each of these are presented below. Refer Appendix B for further information on the outage (and damage) based on both literature review and discussions with the network operator (Chorus).

8.1 Telecommunication exchange buildings

Refer to Appendix B Section 5.1 for further information on outage and damage.

	Hours	Days	Weeks	Months	> 6 months
Volcanic ash (Depth)					
< 5 mm	No impact or disruption expected				
5 -30 mm	■	■			
30 - 100 mm	■	■			
> 100 mm			■	■	

	Hours	Days	Weeks	Months	> 6 months
Flood (Depth)					
< 0.5 m	No impact or disruption expected				
0.5 - 1 m	■	■			
1 - 2 m		■	■		
> 2 m			■	■	

	Hours	Days	Weeks	Months	> 6 months
Tsunami (Depth)					
< 0.1 m	No impact or disruption expected				
0.1 - 1 m	■	■			
1 - 2 m		■	■		
> 2 m			■	■	

	Hours	Days	Weeks	Months	> 6 months
Liquefaction*					
None to Minor	■	■			
Minor to Moderate		■	■		
Moderate to Severe			■	■	

**Classification based on: Planning and engineering guidance for potentially liquefaction-prone land (MBIE, 2017)*

8.2 Overhead telecommunication lines

During discussions with the network operator (Chorus) it was deemed, given the overhead telecommunication lines are elevated, that no damage would likely result from flood hazard. This was based on observations from past events. Therefore, the tables below do not include flood hazard.

Refer to Appendix B Section 5.2 for further information on outage and damage.

	Hours	**Days**	**Weeks**	**Months**	**> 6 months**
Volcanic ash (Depth)					
< 50 mm	No impact or disruption expected				
> 50 mm		■	■		

	Hours	**Days**	**Weeks**	**Months**	**> 6 months**
Tsunami (Depth)					
< 0.2 m	No impact or disruption expected				
0.2 - 0.5 m	■	■			
0.5 – 1		■	■		
> 1 m		■	■		

	Hours	**Days**	**Weeks**	**Months**	**> 6 months**
Liquefaction*					
None to Minor	No impact or disruption expected				
Minor to Moderate		■			
Moderate to Severe		■	■		

*Classification based on: *Planning and engineering guidance for potentially liquefaction-prone land* (MBIE, 2017)

8.3 Buried telecommunication lines

During discussions with the network operator (Chorus) it was deemed, given the telecommunication lines are buried and not exposed, that no damage would likely result from volcanic ashfall. This was based on observations from past events. Therefore, the tables below do not include volcanic ashfall hazard.

Refer to Appendix B Section 5.2 for further information on outage and damage.

	Hours	**Days**	**Weeks**	**Months**	**> 6 months**
Flood (Depth)					
< 0.1 m	No impact or disruption expected				
0.1 - 1 m	■	■			
1 - 2 m		■	■		
> 2 m			■	■	

	Hours	Days	Weeks	Months	> 6 months
Tsunami (Depth)					
< 0.1 m	No impact or disruption expected				
0.1 - 1 m					
1 - 2 m					
> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Liquefaction*					
None to Minor	No impact or disruption expected				
Minor to Moderate					
Moderate to Severe					

*Classification based on: *Planning and engineering guidance for potentially liquefaction-prone land* (MBIE, 2017)

8.4 Telecommunication roadside cabinets

Refer to Appendix B Section 5.1 for further information on outage and damage.

	Hours	Days	Weeks	Months	> 6 months
Volcanic ash (Depth)					
< 5 mm	No impact or disruption expected				
5 -30 mm					
30 - 100 mm					
> 100 mm					

	Hours	Days	Weeks	Months	> 6 months
Flood (Depth)					
< 0.1 m					
0.1 - 2 m					
> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Tsunami (Depth)					
< 0.1 m					
0.1 - 2 m					
> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Liquefaction*					
None to Minor					
Minor to Moderate					
Moderate to Severe					

*Classification based on: *Planning and engineering guidance for potentially liquefaction-prone land* (MBIE, 2017)

8.5 Telecommunication cellular towers

Given cellular towers are elevated, it was deemed that no direct damage would likely result from floods. This was based on experience from past events. Therefore, the tables below do not include flood hazard.

Refer to Appendix B Section 5.3 for further information on outage and damage.

	Hours	Days	Weeks	Months	> 6 months
Volcanic ash (Depth)					
< 30 mm	No impact or disruption expected				
30 - 100 mm					
> 100 mm					

	Hours	Days	Weeks	Months	> 6 months
Tsunami (Depth)					
< 0.5 m	No impact or disruption expected				
0.5 - 2 m					
> 2 m					

	Hours	Days	Weeks	Months	> 6 months
Liquefaction*					
None to Minor	No impact or disruption expected				
Minor to Moderate					
Moderate to Severe					

*Classification based on: *Planning and engineering guidance for potentially liquefaction-prone land* (MBIE, 2017)

9 Gas sector outage

This section presents outage tables for two main asset types within the gas sector – namely: pipes and delivery points / valves. Each of these are presented below. Refer Appendix B for further information on the outage (and damage) based on both literature review and discussions with the network operator (First Gas).

9.1 Pipes

There are two types of pipe materials typically utilised within the gas sector: Larger steel transmission pipes (up to 200mm diameter), and smaller polyethylene (PE) distribution pipes (20-60 mm approx.).

During discussions with the network operator (First Gas) it was deemed that no damage would likely result to steel pipes from floods, tsunami or liquefaction. This was based on experience from past events. Therefore, the tables below relate to PE pipes only.

Refer to Appendix B Section 6.1 for further information on outage and damage.

	Hours	Days	Weeks	Months	> 6 months
Flood (Depth)					
< 2.5 m	No impact or disruption expected				
> 2.5 m		■			

	Hours	Days	Weeks	Months	> 6 months
Tsunami (Depth)					
< 0.5 m	No impact or disruption expected				
0-5 - 2.5 m		■			
> 2.5 m		■	■		

	Hours	Days	Weeks	Months	> 6 months
Liquefaction*					
None to Minor	■				
Minor to Moderate		■	■		
Moderate to Severe			■	■	

*Classification based on: *Planning and engineering guidance for potentially liquefaction-prone land* (MBIE, 2017)

9.2 Delivery points and valves

Refer to Appendix B Section 6.2 for further information on outage and damage.

	Hours	Days	Weeks	Months	> 6 months
Flood (Depth)					
< 0.1 m	No impact or disruption expected				
> 0.1 m		■			

	Hours	Days	Weeks	Months	> 6 months
Tsunami (Depth)					
< 0.1 m	No impact or disruption expected				
0.1 - 0.5 m		█			
> 0.5 m			█		

	Hours	Days	Weeks	Months	> 6 months
Liquefaction*					
None to Minor		█			
Minor to Moderate		█	█		
Moderate to Severe			█	█	

*Classification based on: *Planning and engineering guidance for potentially liquefaction-prone land* (MBIE, 2017)

10 Summary and areas of further work

This guidance report has been developed for BOPRC in order to facilitate an assessment of 'consequence' for lifelines utilities as part of the risk-based assessment methodology developed within their Regional Policy Statement.

A simple 4-step process has been developed which:

1. Firstly determines if an asset is likely affected or unaffected by a particular hazard.
2. Estimates the number of people potentially affected by the outage (either >20% or <20% of the population), and;
3. Estimates a possible outage time (months, weeks, days etc).
4. Uses the outputs from step 2 and 3 to determine a 'consequence' rating to assess risk in accordance with the natural hazard provisions of the RPS.

The purpose of the risk assessment is to inform natural hazard risk reduction planning in the Bay of Plenty.

Through discussions with the network operators and BOPRC during the development of this report, two areas of further work were identified. These areas of further work will assist the understanding of risk and outage relating to natural hazard impacts on infrastructure, both for BOPRC and more widely around New Zealand.

1. Investigate the development of a nationally consistent classification for damaged utilities. This will enable consistent damage descriptors and damage states
2. Investigate the development of nationally consistent criticality principles/criteria and a rating system, for different infrastructure sectors.

Further work is also required to understand the spatial distribution of landslide hazard in the Bay of Plenty region, and the potential impact this hazard poses to the region's critical lifeline infrastructure.

11 Applicability

This report has been prepared for the exclusive use of our client Bay of Plenty Regional Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Tonkin & Taylor Ltd

Report prepared by:	Authorised for Tonkin & Taylor Ltd by:
....	....
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Appendix A: Outage duration assessment methodology

To understand the restoration times following one of the defined hazardous events, research was conducted to understand estimated degrees of damage for different asset types from increasing hazard intensity. Given the different components that make up the various lifelines services (each with their own vulnerability characteristics), a range of individual assets within the network were evaluated. It is noted that only significant asset types were chosen, based on discussions with experts.

Published literature focusses predominantly on damage and damage/vulnerability *functions* for the various lifeline utilities and hazards. Damage/vulnerability functions are produced through the collection of observed damage (post disaster), laboratory experiments, expert judgment and/or a combination of these. Damage/vulnerability functions produce a damage *factor* or probability of reaching a damage *state*, both of which can often correlate to a damage *descriptor*.

Both New Zealand and international research were reviewed for its applicability to this project. International case studies were only considered where the network and environment is analogous with New Zealand.

Generally, restoration times are inferred using the damage descriptors for a given hazard intensity, as well as expert operational and engineering expertise. Given the uncertainty involved in post disaster restoration, restoration times are often given as broad ranges. Consideration is made in the ranges for variables such as resourcing and extent of damage from the hazardous event.

For the purpose of this work, restoration time is defined as: *the time taken for the asset to be restored to original capacity via repair, remedial solution or replacement*. It should be assumed that the hazardous event is over and access is restored. Note restoration in this context does not include temporary solutions e.g. supply of portable toilets in response to wastewater outage.

Given some of the hazards will not result in damage to certain types of lifeline utility infrastructure, restoration times are only determined where damage is thought to be possible. A summary table is provided within the body of the report which lists the sectors and individual asset types for which damage is considered possible, and where restoration times have been assessed.

Network operators from the various lifeline providers from across the region were consulted to provide estimates on outage duration for critical assets within the lifeline networks:

- Water supply/Wastewater – Tauranga City Council (TCC)
- Power – Transpower and Horizon Energy
- Road transportation – TCC and Western Bay of Plenty District Council
- Telecommunications –Chorus
- Gas – First Gas

Outage time information was also sourced from expert workshops with lifeline utility providers:

- 22 June 2017 – Bay of Plenty Lifelines Group Workshop: Natural Hazards Consequences
- 6 March 2018 – NIWA Workshop: Flood Vulnerability Expert Elicitation.

Appendix B: Asset damage discussion

1 Power sector

Below we summarise literature relating to the main types and degrees of *damage* which may occur for power sector assets from the various hazards. The power sector assets include: substation, power lines (overhead on poles, overhead on pylon and buried) and power generation sites. These damage descriptions were then utilised in discussion with the utility operator to estimate outage times.

1.1 Substation

Hazard	Damage discussion
Volcanic ash	Substations are susceptible to a range of impacts from increasing volcanic ashfall thickness. These range from insulator flashover requiring clean up, to substantial repair and replacement due to ash loading and abrasion to components (Wilson et al., 2014). Differences in the impacts can arise from ash thickness, the chemical composition of the ash (which can influence corrosion), and weather conditions (as rain causes sedimentation and increasing loading, even at small thicknesses). Restoration times are related to the degree of damage as well as the amount of time required to restore services. Damage/vulnerability functions generated by Wilson et al (2017) are used to infer damage to substations from increasing ashfall thicknesses: • 3 - 10 mm: Possible abrasion of moving parts, infiltration of substation gravels. • 10 - 100 mm: Electrical component break, corrosion of circuits and damage to exposed equipment. • > 100 mm: Irreparable damage to moving parts, structural damage to equipment. Discussion with the network operators found the level of damage is dependent on the ability to seal and turn off the HVAC system, but keeping the equipment cool to maintain operation over prolonged periods of ashfall, will be difficult.
Flooding	Flood events can inundate exposed substations resulting in damage ranging from silt deposition requiring clean up to damage to components and housing structures. Flood damage is related to both the flood depth and flood velocity - however, most damage models use flood depth as a metric to indicate variability in the potential damage. It is noted that at the time of writing this report, damage functions for power assets were being investigated by NIWA, following an expert elicitation workshop with power utilities (6 March 2018). During the workshop the substation was damage was considered in relation to key components such as transformers, capacitor banks and telecommunications. For the purposes of this assessment, an overall average damage was applied, given the variability in substation configuration: • < 0.3 m: No damage or disruption to service, potential minor clean up. • 0.3 – 2 m: Clean up and minor repairs with safety checks. • > 2 m: Components shorted if not turned off prior, extensive repairs and replacement. Discussion with the network operators found damage is site dependent given critical components are at different levels above ground level. Outage duration is dependent on the availability of replacement components.
Tsunami	Tsunamis can result in significant damage and outage times for substations. At small inundation depths, tsunamis cause water and salt damage to components and bring debris and silt deposition, at deeper inundation depths assets can be washed away and

	destroyed. Tsunami damage is related to both inundation depth and flow velocity. Tsunamis can bring with them debris from offshore and near the coast, and high velocities can support large pieces of debris, which can severely impact assets. Restoration times are related to the degree of damage as well as the amount of time required to restore services. Damage functions generated by Horspool and Fraser (2015) are used to infer damage to substations from increasing tsunami inundation depths: • < 0.1 m: Debris, likely small, deposition and exposed assets damage. • 0.1 – 0.5 m: Debris deposition, small impact damage and structural damage. • 0.5 - 2.5 m: Impact damage and structural damage to the housing, scouring of the land and even smaller assets being washed away. • > 2.5 m: Components washed away.
Liquefaction	Liquefaction can be potentially damaging to substations. Damage has been characterised using Tonkin + Taylor expertise and observations following the Christchurch Earthquake Sequence, as there is little documented damage at this stage for lifelines and infrastructure. For the purposes of this study, it is assumed a shaking level that would induce liquefaction has occurred. Restoration times are related to the degree of damage as well as the amount of time required to restore services. Damage characterisation shows expected damage to substations from increasing levels of liquefaction land damage categories (defined by Tonkin + Taylor, 2015): • None to Minor: Oscillation damage. • Minor to Moderate: Punching into the ground up to 200 mm, potential subsequent flooding, tilting typically < 100 mm over footprint. • Moderate to Severe: Punching into the ground up to 1 m, potential subsequent flooding, tilting, stretching of components (external yard).

1.2 Power lines – overhead on poles

Hazard	**Damage discussion**
Volcanic ash	Overhead power lines are susceptible to a range of impacts from increasing volcanic ashfall thickness. These range from insulator flashover requiring clean up to substantial repair and replace from ash loading and even line breakage (Wilson et al., 2014). Differences in the impacts can arise from the chemical composition of the ash (causing corrosion), as well as weather, as rain causes sedimentation and increased loading, even at small thicknesses. Restoration times are related to the degree of damage as well as the amount of time required to restore services. Damage functions generated by Wilson et al (2017) are used to infer damage to overhead power lines from increasing ashfall thicknesses: • 3 - 10 mm: Insulator flashover potential if wet. • 10 - 100 mm: Potential ash welding on insulators and pylons. • > 100 mm: Line breakages due to ash loading. Discussion with the network operators found flashover potential is dependent on the orientation of insulators for ash settlement and the intensity of rainfall as heavy rainfall will most likely wash the surface, while light rainfall is more likely to result in sedimentation and welding leading to flashover.
Flooding	Flood events can impact exposed overhead power lines and poles resulting in damage ranging from silt deposition requiring clean up to damage to components and housing structures. Flood damage related to both the flood depth and flood flow velocity.

	However, most damage models use flood depth as a metric to indicate variability in the potential damage. As described above, damage functions for power assets are being investigated by NIWA. For the purposes of this assessment, and following the NIWA workshop, the following damage descriptors are proposed: • < 0.3 m: No to light impact damage to pylons and poles. • 0.3 – 2 m: Line checks and cleaning, light impact damage to pylons and poles. • > 2 m: More severe damage could be possible, including scour at base of poles/towers. Tower and pole check and repairs, dependent on impact damage.
Tsunami	Tsunamis can result in significant damage to power lines. At small inundation depths, tsunamis cause damage to components and bring debris and silt deposition, at deeper inundation depths. Tsunami damage is sensitive to both inundation depth and flow velocity. Tsunamis can bring with them debris from offshore and near the coast, and high velocities can support large pieces of debris, which can severely impact assets. Damage functions generated by Horspool and Fraser (2015) are used to infer damage (and outline damage descriptors) relating to overhead power lines from increasing tsunami inundation depths: • < 0.5 m: Light impact damage to pylons and poles. • 0.5 – 3 m: Heavier impact damage to pylons and poles. • > 3 m: Significant impact and potential for structures being washed away at depths, land scour damage to buried infrastructure.
Liquefaction	Liquefaction can be potential damaging to buried power lines. Damage is characterised using Tonkin + Taylor expertise and observations following the Christchurch Earthquake Sequence as there is little documented damage at this stage for lifelines and infrastructure. For the purposes of this, it is assumed a shaking level that would induce liquefaction has occurred. Damage characterisation shows expected damage to buried power lines from increasing levels of liquefaction land damage categories (defined by Tonkin + Taylor, 2015): • None to Minor: Oscillation damage, 0.5-1 m movement in the poles, interference with trees, line breakages. • Minor to Moderate: Settlement of poles at angles (leaning), stretching in cables. • Moderate to Severe: Leaning, sinking and movement of poles, stretch in the cables. If poles span over waterway, likely lean towards each other and potential ground contact.

1.3 Power lines – overhead on pylons

Hazard	Damage discussion
Volcanic ash	Overhead power lines are susceptible to a range of impacts from increasing volcanic ashfall thickness. These range from insulator flashover requiring clean up to substantial repair and replace from ash loading and even line breakage (Wilson et al., 2014). Differences in the impacts can arise in the chemical composition of the ash (causing corrosion) as well as weather, as rain causes sedimentation and increased loading, even at small thicknesses. Restoration times are related to the degree of damage as well as the amount of time required to restore services. Damage functions generated by Wilson et al (2017) are used to infer damage to overhead power lines from increasing ashfall thicknesses: • 3 - 10 mm: Insulator flashover potential if wet.

	• 10 - 100 mm: Potential ash welding on insulators and pylons. • > 100 mm: Line breakages due to ash loading.
Flooding	Flood events can impact exposed overhead power lines and pylons resulting in damage ranging from silt deposition requiring clean up to damage to components and housing structures. Flood damage is sensitive to both the flood depth and flood flow velocity. However, most damage models use flood depth as a metric to indicate variability in the potential damage. As described above, damage functions for power assets are being investigated by NIWA. For the purposes of this assessment, and following the NIWA workshop, the following damage descriptors are proposed: • < 0.3 m: No to light impact damage to pylons and poles. • 0.3 – 2 m: Line checks and cleaning, light impact damage to pylons and poles. • > 2 m: Tower and pole check and repairs, dependent on impact damage Tower and pole check and repairs, dependent on impact damage.
Tsunami	Tsunamis can result in significant damage to power pylons. At small inundation depths, tsunamis cause damage to components and bring debris and silt deposition, at deeper inundation depths. Tsunami damage is sensitive to both inundation depth and flow velocity. Tsunamis can bring with them debris from offshore and near the coast, and high velocities can support large pieces of debris, which can severely impact assets. Damage functions generated by Horspool and Fraser (2015) are used to infer damage to overhead power lines from increasing tsunami inundation depths: • < 0.5 m: Light impact damage to pylons and poles. • 0.5 – 3 m: Heavier impact damage to pylons and poles. • > 3 m: Significant impact and potential for structures being washed away at depths, land scour damage to buried infrastructure.
Liquefaction	Liquefaction can be potentially damaging to power pylons. Damage is characterised using Tonkin + Taylor expertise and observations following the Christchurch Earthquake Sequence as there is little documented damage at this stage for lifelines and infrastructure. For the purposes of this, it is assumed a shaking level that would induce liquefaction has occurred. Damage characterisation shows expected damage to pylons from increasing levels of liquefaction land damage categories (defined by Tonkin + Taylor, 2015): • None to Minor: Oscillation damage, 0.5-1 m movement in the pylons, interference with trees, line breakages. • Minor to Moderate: Settlement of pylons at angles (leaning), stretching in cables. • Moderate to Severe: Leaning, sinking and movement of pylons, stretch in the cables. If pylons span over waterway, likely lean towards each other and potential ground contact.

1.4 Power lines - buried

Hazard	Damage discussion
Flooding	Flood can result in damage and outage to buried power lines, which are encased in either PVC or AC pipes. At small inundation depths, floods can cause minor siltation requiring clean up through to deeper inundation depths resulting in land scour and breakages. Flood damage to buried power lines largely related to flood velocity – however higher velocities often occur during very large flood events – hence for simplicity, a depth function is proposed.

	As described above, damage functions for power assets are being investigated by NIWA. For the purposes of this assessment, and following the NIWA workshop, the following damage descriptors are proposed: • < 2 m it is not likely there will be damage as the infrastructure is buried. • > 2 m it is not likely there would be damage, however if the pipe is washed out was from scouring, outage would be significant.
Tsunami	Tsunamis can result in damage and outage to buried power lines, which are encased in either PVC or AC pipes. At small inundation depths, tsunamis can cause minor siltation requiring clean up through to deeper inundation depths resulting in land scour and breakages. Tsunami damage is sensitive to both inundation depth and flow velocity. Tsunamis can bring with them debris from offshore and near the coast, and high velocities can support large pieces of debris, which can severely impact assets. Damage functions for tsunami to buried power lines do not exist. In the absence of damage functions, water pipe functions are assessed given the similarity of likely damage and the fact that cables are generally laid in external ducts. Damage functions generated by Horspool and Fraser (2015) and Williams (2016) are used to infer damage to buried power lines from increasing tsunami inundation depths: • < 0.5 m: Silt infiltration, none to minor damage for buried power lines. • 0.5 - 2 m: Scour of weak backfill and cable casing fractures. • > 2 m: Land scour, cable casing breakages and wash out of assets resulting in line breakages, this is likely very rare given the depth and velocities required.
Liquefaction	Liquefaction can be potentially damaging to buried power lines, which are typically encased in PVC or AC pipes. Damage is characterised using Tonkin + Taylor expertise and observations following the Christchurch Earthquake Sequence as there is little documented damage at this stage for lifelines and infrastructure. For the purposes of this, it is assumed a shaking level that would induce liquefaction has occurred. Damage characterisation shows expected damage to buried power lines from increasing levels of liquefaction land damage categories (defined by Tonkin + Taylor, 2015): • None to Minor: Oscillation damage (Small impact). • Minor to Moderate: Some stretching and bending < 50 mm over 10 m. • Moderate to Severe: More severe stretching and bending ground/cables > 100 mm over 10 m.

1.5 Power generation sites

While it is acknowledged the different power generation methods (e.g. geothermal and hydropower) each have their own unique vulnerability characteristics, for the purposes of this assessment, the damage to generic power generation site components have been considered when assessing damage and subsequent outage.

Hazard	**Damage discussion**
Volcanic ash	Power generation sites are susceptible to a range of impacts from increasing volcanic ashfall thickness. These range from insulator flashover requiring clean up to substantial repair and replace from ash loading and abrasion to components (Wilson et al., 2014). Differences in the impacts can arise in the chemical composition causing corrosion as well as weather, as rain causes sedimentation, increasing loading, even at small thicknesses. Restoration times are based on the degree of damage as well as the amount of time required to restore services. Damage functions generated by Wilson et al (2017) are used to infer damage to power generation sites from increasing ashfall thicknesses:

	• 3 – 10 mm: Possible abrasion of moving parts. • 10 – 100 mm: Electrical component break, corrosion of circuits and damage to exposed equipment. • >100 mm: Irreparable damage to moving parts, structural damage to equipment.
Flooding	Flood events can inundate exposed power generation sites resulting in damage ranging from silt deposition requiring clean up to damage to components and housing structures. Flood damage is related to both the flood depth and flood flow velocity. However, most damage models use flood depth as a metric to indicate variability in the potential damages. As described above, damage functions for power assets are being investigated by NIWA. For the purposes of this assessment, and following the NIWA workshop, the following damage descriptors are proposed: • 0.3 - 2 m: Debris inundation, siltation, clean-up and repairs. • > 2 m: Major repair/destruction of the site resulting in substantial outage. Discussion with network providers found that the outage duration is dependent on the availability of replacement components.
Tsunami	Tsunamis can result in significant damage and outage times for power generation sites. At small inundation depths, tsunamis can cause minor siltation requiring clean up through to deeper inundation depths resulting in land scour and breakages. Tsunami damage is related to both inundation depth and flow velocity. Tsunamis can bring with them debris from offshore and near the coast, and high velocities can support large pieces of debris, which can severely impact assets. Damage functions generated by Horspool and Fraser (2015) are used to infer damage to power generation sites from increasing tsunami inundation depths: • < 0.1 m: Debris, likely small, deposition and exposed assets damage. • 0.1–0.5 m: Debris deposition, small impact damage and structural damage. • 0.5-2.5 m: Structural damage, impact damage, damage to the housing structures, scouring of the land and even smaller assets being washed away. • > 2.5 m: Components washed away.
Liquefaction	Liquefaction can be potential damaging to power generation sites. Damage has been broadly characterised using Tonkin + Taylor expertise and observations following the Christchurch Earthquake Sequence as there is little documented damage at this stage for lifelines and infrastructure. For the purposes of this, it is assumed a shaking level that would induce liquefaction has occurred. Damage characterisation shows expected damage to power generation sites from increasing levels of liquefaction land damage categories (defined by Tonkin + Taylor, 2015): • None to Minor: Oscillation damage. • Minor to Moderate: Punching into the ground up to 200 mm, potential subsequent flooding, tilting typically < 100 mm over footprint. • Moderate to Severe: Punching into the ground up to 1 m, potential subsequent flooding, tilting and stretching of components (external yard).

2 Water supply sector

Below we summarise literature relating to the main types and degrees of *damage* which may occur for water supply assets from the various hazards. The water supply assets include: treatment plant sites, pump stations, reservoirs, pipes and both surface and groundwater intakes. These damage descriptions were then utilised in discussion with the utility operator to estimate outage times.

2.1 Water treatment plants

Hazard	**Damage discussion**
Volcanic ash	Water treatment plants are susceptible to a range of impacts from increasing volcanic ashfall thickness. At small thicknesses, impacts are likely to be clogging and abrasion, with larger thicknesses leading to a potential collapse of structures (Wilson et al., 2014). Differences in the impacts can arise due to the chemical composition (causing corrosion) as well as weather, as rain can cause sedimentation to occur on components. Restoration times are related to the degree of damage as well as the amount of time required to restore services. Damage functions generated by Wilson et al (2017) are used to infer damage to water treatment plants from increasing ashfall thicknesses: • 3 - 20 mm: Clogging of exposed filters, possible abrasion of moving components. • 20 - 100 mm: Contamination of facility, damage to exposed equipment water contamination increasing strain on equipment. • > 100 mm: Irreparable damage to moving parts, structural damage to equipment.
Flooding	Flood events can inundate exposed water treatment facilities resulting in damage ranging from silt deposition requiring clean up through to collapse of housing structures and equipment being washed away. Flood damage is sensitive to both the flood depth and flood flow velocity. However, most damage models use flood depth as a metric indicating variability in the potential damages. Damage functions generated by Reese and Ramsay (2009) are used to infer damage to water treatment plants from increasing flood depths: • < 0.5 m: Debris deposition and exposed asset damage e.g. motors. • 0.5 – 2 m: Debris deposition, small impact damage and structural damage. • > 2 m: Structural damage, impact damage, damage to the housing structures, scouring of the land and even assets being washed away.
Tsunami	Tsunamis can result in significant damage and outage times for treatment plants. At small inundation depths, tsunamis bring debris and silt deposition requiring clean up, through to deeper inundation depths resulting in equipment being washed away. Tsunami damage is sensitive to both inundation depth and flow velocity. Tsunamis can bring with them debris from offshore and near the coast, and high velocities can support large pieces of debris, which can severely impact assets. Damage functions generated by Horspool and Fraser (2015) are used to infer damage to water treatment plants from increasing tsunami inundation depths: • < 0.5 m: Debris, likely small, deposition, salt contamination and exposed assets damage. Still require substantial clean up and repairs. • 0.5 - 2 m: Water contamination, equipment damaged and washed away. • > 2 m: Components washed away, structural damage.
Liquefaction	Liquefaction can be potential damaging to water treatment plants. Damage is characterised using Tonkin + Taylor expertise and observations following the Christchurch Earthquake Sequence as there is little documented damage at this stage for

	lifelines and infrastructure. For the purposes of this, it is assumed a shaking level that would induce liquefaction has occurred. Damage characterisation shows expected damage to water treatment plants from increasing levels of liquefaction land damage categories (defined by Tonkin + Taylor, 2015): • None to Minor: Oscillation damage. • Minor to Moderate: Punching into the ground up to 200 mm, potential subsequent flooding, tilting typically < 100 mm over footprint, surface cracking. • Moderate to Severe: Punching into the ground up to 1 m, potential subsequent flooding, tilting, stretching of components (external yard), surface cracking and ejecta.

2.2 Pump stations

Hazard	Damage discussion
Volcanic ash	Pump stations are susceptible to a range of impacts from increasing volcanic ashfall thickness. At small thicknesses, impacts are likely to be clogging and abrasion ranging up to collapse of structures (Wilson et al., 2014). Differences in the impacts can arise due to the chemical composition causing corrosion as well as weather, as rain causes sedimentation on components. Restoration times are based on the degree of damage as well as the amount of time required to restore services. Damage functions generated by Wilson et al (2017) are used to infer damage to pump stations from increasing tsunami inundation depths: • > 5 mm: Clogging of exposed filters and possible abrasion of moving components. Reduced output. Need to clean and replace components.
Flooding	Flood events can inundate exposed pump stations resulting in damage ranging from silt deposition requiring clean up through to collapse of the housing structures and equipment being washed away. Flood damage is sensitive to both the flood depth and flood flow velocity. However, most damage models use flood depth as a metric indicating variability in the potential damages. Damage functions generated by Reese and Ramsay (2009) are used to infer damage to pump stations from increasing flood depths: • < 0.5 m: Debris deposition and exposed asset damage e.g. motors. • 0.5 – 2 m: Debris deposition, small impact damage and structural damage. • > 2 m: Structural damage, impact damage, damage to the housing structures, scouring of the land and even assets being washed away.
Tsunami	Tsunamis can result in significant damage and outage times for pump stations. At small inundation depths, tsunamis brings with it debris and silt deposition requiring clean up through to deeper inundation depths resulting in equipment being washed away. Tsunami damage is sensitive to both inundation depth and flow velocity. Tsunamis can bring with them debris from offshore and near the coast, and high velocities can support large pieces of debris, which can severely impact assets. Damage functions generated by Horspool and Fraser (2015) are used to infer damage to pump stations from increasing tsunami inundation depths: • < 0.5 m: Debris, likely small, deposition, salt contamination and exposed assets damage. • 0.5 - 2 m: Water contamination, equipment damaged and washed away. • > 2 m: Components washed away, structural damage.

Liquefaction	Liquefaction can be potential damaging to pump stations. It is assumed pump station held in underground cavity. Damage is characterised using Tonkin + Taylor expertise and observations following the Christchurch Earthquake Sequence as there is little documented damage at this stage for lifelines and infrastructure. For the purposes of this, it is assumed a shaking level that would induce liquefaction has occurred. Damage characterisation shows expected damage to pump stations from increasing levels of liquefaction land damage categories (defined by Tonkin + Taylor, 2015): • None to Minor: Oscillation damage (minor impact). • Minor to Moderate: Some uplift (dependent on the ground cavity), strain incoming pipe connections. Sediment ingress leading to increased abrasion and wear in the motors. • Moderate to Severe: Significant uplift, breakages to incoming pipe connections, flooding. Sediment ingress leading to increased abrasion and wear in the motors.

2.3 Reservoir

Hazard	Damage discussion
Volcanic ash	Reservoirs damage following exposure to volcanic ashfall can vary depending on the experience thickness. At small thicknesses, impacts are likely to be clogging of filters and contamination of water ranging up to collapse of structures (Wilson et al., 2014). Differences in the impacts can arise in the chemical composition and rain causes sedimentation and increases loading. Restoration times are based on the degree of damage as well as the amount of time required to restore services. Damage was inferred after from Wilson et al. (2017) used to infer damage to reservoirs from increasing volcanic ash thicknesses. Following discussion with TCC, the assumption is made that all reservoirs are closed with concrete roofs – so only a major ashfall may impact (causing roof collapse): • > 100 mm: Roof collapse and infilling of reservoirs leading to irreparable damage to moving parts, structural damage to equipment.
Liquefaction	Liquefaction can be potentially damaging to reservoirs. Damage is characterised using Tonkin + Taylor expertise and observations following the Christchurch Earthquake Sequence as there is little documented damage at this stage for lifelines and infrastructure. For the purposes of this, it is assumed a shaking level that would induce liquefaction has occurred. Damage characterisation shows expected damage to reservoirs from increasing levels of liquefaction land damage categories (defined by Tonkin + Taylor, 2015): • None to Minor: Oscillation damage (minor impact). • Minor to Moderate: Potential for moderate, global and differential sediment. • Moderate to Severe: Potential for severe global and differential settlement, significant tilting leading to loss of support due to large cavity forming, potential leaking and even catastrophic failure.

2.4 Pipes

Hazard	Damage discussion
Flooding	Flooding can result in significant damage to water supply pipes. At small inundation depths, floods brings with it debris and silt deposition requiring clean up through to deeper inundation depths resulting in equipment being washed away. Flood damage is sensitive to both inundation depth and flow velocity. There is no damage function for pipes exposed to flooding. The inundation from tsunami is likely conservative, but analogous for flooding. Damage functions generated by Horspool and Fraser (2015) and Williams (2016) are used to infer damage to pipes from increasing tsunami inundation depths: • < 0.5 m: Silt infiltration. • 0.5 - 2 m: Debris contamination of the water, scour of weak backfill and pipe fractures. • > 2 m: Land scour and pipe breakages.
Tsunami	Tsunamis can result in significant damage to water supply pipes. At small inundation depths, tsunamis can cause minor siltation requiring clean up through to deeper inundation depths resulting in land scour and breakages. Tsunami damage is sensitive to both inundation depth and flow velocity. Tsunamis can bring with them debris from offshore and near the coast, and high velocities can support large pieces of debris, which can severely impact assets. Damage functions generated by Horspool and Fraser (2015) and Williams (2016) are used to infer damage to pipes from increasing tsunami inundation depths: • < 0.5 m: Silt infiltration. • 0.5 - 2 m: Debris contamination of the water, scour of weak backfill and pipe fractures. • > 2 m: Land scour and pipe breakages.
Liquefaction	Liquefaction can be potential damaging to water supply pipes. Damage is characterised using Tonkin + Taylor expertise and observations following the Christchurch Earthquake Sequence as there is little documented damage at this stage for lifelines and infrastructure. For the purposes of this, it is assumed a shaking level that would induce liquefaction has occurred. Damage characterisation shows expected damage to three waters pipes from increasing levels of liquefaction land damage categories (defined by Tonkin + Taylor, 2015): • None to Minor: Oscillation damage (impact small), controlled by Peak Ground Velocity (PGV): lower (0.1 break/km); higher (1 break/km). PVC approximately a factor of 10 less than AC and CI. • Minor to Moderate: 5 to 20 times increase of pipe break of none to minor, PVC lower end of range, AC at the high end of range. Differential settlement and potential reductions in pipe gradients. Some ingress of sediment into pipes. • Moderate to Severe: 10 to 50 times increase of pipe break of none to minor, PVC lower end of range, AC at the high end of range. Differential settlement and change in pipe gradient impacts. Significant ingress of sediment into pipes.

2.5 Groundwater intakes

Hazard	Damage discussion
Volcanic ash	Groundwater intakes using bores and pumps are susceptible to a range of impacts from increasing volcanic ashfall thickness. At small thicknesses, impacts are likely to be clogging and abrasion ranging up to collapse of structures (Wilson et al., 2014). Differences in the impacts can arise due to the chemical composition causing corrosion as well as weather, as rain causes sedimentation on components. Restoration times are based on the degree of damage as well as the amount of time required to restore services. Damage functions do not exists for groundwater intakes, but given the similarity in vulnerability, data from pump stations generated by Wilson et al (2017) are used to infer damage to groundwater intakes from increasing tsunami inundation depths: • 5 - 20 mm: Clogging of exposed filters and possible abrasion of moving components, loss of power. • 20 - 100 mm: Contamination of facility and damage to exposed pumping equipment. • > 100 mm: Irreparable damage to moving parts, structural damage to equipment
Flooding	Flood events can inundate exposed groundwater intakes resulting in damage ranging from silt deposition requiring clean up through to collapse of the housing structures and equipment being washed away. Flood damage is sensitive to both the flood depth and flood flow velocity. However, most damage models use flood depth as a metric indicating variability in the potential damages. There is no damage reports groundwater intakes, but given the similarity in infrastructure damage functions for pump stations generated by Reese and Ramsay (2009) are used to infer damage to pump stations from increasing flood depths: • < 0.5 m: Debris deposition and exposed asset damage e.g. motors. • 0.5 – 2 m: Debris deposition, small impact damage and structural damage. • > 2 m: Structural damage, impact damage, damage to the housing structures, scouring of the land and even assets being washed away.
Tsunami	Tsunamis can result in significant damage and outage times for groundwater intakes using pumps and bores. At small inundation depths, tsunamis brings with it debris and silt deposition requiring clean up through to deeper inundation depths resulting in equipment being washed away. Tsunami damage is sensitive to both inundation depth and flow velocity. Tsunamis can bring with them debris from offshore and near the coast, and high velocities can support large pieces of debris, which can severely impact assets. There is no damage reports groundwater intakes, but given the similarity in infrastructure damage functions for pump stations generated by Horspool and Fraser (2015) are used to infer damage to pump stations from increasing tsunami inundation depths: • < 0.5 m: Debris, likely small, deposition, salt contamination and exposed assets damage. • 0.5 - 2 m: Water contamination, equipment damaged and washed away. • > 2 m: Components washed away, structural damage.
Liquefaction	Liquefaction can be potential damaging to groundwater intakes. Damage is characterised using Tonkin + Taylor expertise and observations following the Christchurch Earthquake Sequence as there is little documented damage at this stage for lifelines and infrastructure. For the purposes of this, it is assumed a shaking level that would induce liquefaction has occurred.

	Damage characterisation shows expected damage to groundwater intakes from increasing levels of liquefaction land damage categories (defined by Tonkin + Taylor, 2015): • None to Minor: Oscillation damage (minor impact). • Minor to Moderate: Some uplift (dependent on the ground cavity), strain incoming pipe connections. Sediment ingress leading to increased abrasion and wear in the motors. • Moderate to Severe: Significant uplift, breakages to incoming pipe connections, flooding. Sediment ingress leading to increased abrasion and wear in the motors.

2.6 Surface water intakes

Hazard	Damage discussion
Volcanic ash	Surface water intakes using bores and pumps are susceptible to a range of impacts from increasing volcanic ashfall thickness. At small thicknesses, impacts are likely to be clogging and abrasion ranging up to collapse of structures from ash contamination in the water (Wilson et al., 2014). Differences in the impacts can arise due to the chemical composition causing corrosion as well as weather, as rain causes sedimentation on components. Restoration times are based on the degree of damage as well as the amount of time required to restore services. Damage functions do not exists for groundwater intakes, but given the similarity in vulnerability, data from pump stations generated by Wilson et al (2017) are used to infer damage to groundwater intakes from increasing tsunami inundation depths: • 5 - 20 mm: Clogging of exposed filters and possible abrasion of moving components. • 20 - 100 mm: Contamination of facility and damage to exposed pumping equipment. • > 100 mm: Irreparable damage to moving parts, structural damage to equipment.
Flooding	Flood events can inundate exposed surface water intakes resulting in damage ranging from silt deposition requiring clean up through to collapse of the housing structures and equipment being washed away. Flood damage is sensitive to both the flood depth and flood flow velocity. However, most damage models use flood depth as a metric indicating variability in the potential damages. There is no damage reports surface water intakes, but given the similarity in infrastructure damage functions for pump stations generated by Reese and Ramsay (2009) are used to infer damage to pump stations from increasing flood depths: • < 0.5 m: Debris deposition and exposed asset damage e.g. motors. • 0.5 – 2 m: Debris deposition, small impact damage and structural damage. • > 2 m: Structural damage, impact damage, damage to the housing structures, scouring of the land and even assets being washed away.
Tsunami	Tsunamis can result in significant damage and outage times for surface water intakes. At small inundation depths, tsunamis brings with it debris and silt deposition requiring clean up through to deeper inundation depths resulting in equipment being washed away. Tsunami damage is sensitive to both inundation depth and flow velocity. Tsunamis can bring with them debris from offshore and near the coast, and high velocities can support large pieces of debris, which can severely impact assets. There are no damage reports for surface water intakes, but given the similarity in infrastructure damage functions for pump stations generated by Horspool and Fraser

	(2015) are used to infer damage to pump stations from increasing tsunami inundation depths: • < 0.5 m: Debris, likely small, deposition, salt contamination and exposed assets damage. • 0.5 - 2 m: Water contamination, equipment damaged and washed away. • > 2 m: Components washed away, structural damage.
Liquefaction	Liquefaction can be potential damaging to surface water intakes. Damage is characterised using Tonkin + Taylor expertise and observations following the Christchurch Earthquake Sequence as there is little documented damage at this stage for lifelines and infrastructure. For the purposes of this, it is assumed a shaking level that would induce liquefaction has occurred. Damage characterisation shows expected damage to surface water intakes from increasing levels of liquefaction land damage categories (defined by Tonkin + Taylor, 2015): • None to Minor: Oscillation damage (minor impact). • Minor to Moderate: Some uplift (dependent on the ground cavity), strain incoming pipe connections. Sediment ingress leading to increased abrasion and wear in the motors. • Moderate to Severe: Significant uplift, breakages to incoming pipe connections, flooding. Sediment ingress leading to increased abrasion and wear in the motors.

3 Wastewater sector

Below we summarise literature relating to the main types of *damage* which may occur for wastewater assets from the various hazards. The wastewater assets include: treatment plant sites, pump stations, and pipes. These damage descriptions were then utilised in discussion with the utility operator to estimate outage times.

3.1 Treatment plants

Hazard	**Damage discussion**
Volcanic ash	Water treatment plants are susceptible to a range of impacts from increasing volcanic ashfall thickness. At small thicknesses, impacts are likely to be clogging and abrasion ranging up to collapse of structures (Wilson et al., 2014). Differences in the impacts can arise due to the chemical composition causing corrosion as well as weather, as rain causes sedimentation on components. Restoration times are based on the degree of damage as well as the amount of time required to restore services. Damage functions generated by Wilson et al (2017) are used to infer damage to water treatment plants from increasing ashfall thicknesses: • 3 – 10 mm: Possible minor abrasion and clogging of exposed filters. • 10 – 50 mm: Large amounts of sedimentation in network causing blockages, damage to component and infilling of open tanks. Might be required to discharge of untreated sewage as there is a need to clean and unblock. • > 50 mm: Irreparable damage to moving parts, structural damage to equipment, widespread sedimentation and blockages. Unable to treat wastewater as a result of long term to possible permanent disruption.
Flooding	Flood events can inundate exposed water treatment facilities resulting in damage ranging from silt deposition requiring clean up through to collapse of housing structures and equipment being washed away. Flood damage is sensitive to both the flood depth and flood flow velocity. However, most damage models use flood depth as a metric indicating variability in the potential damages. Damage functions generated by Reese and Ramsay (2009) are used to infer damage to water treatment plants from increasing flood depths: • < 0.5 m: Debris deposition and exposed asset damage e.g. motors. • 0.5 – 2 m: Debris deposition, small impact damage and structural damage. • > 2 m: Structural damage, impact damage, damage to the housing structures, scouring of the land and even assets being washed away.
Tsunami	Tsunamis can result in significant damage and outage times for treatment plants. At small inundation depths, tsunamis brings with it debris and silt deposition requiring clean up through to deeper inundation depths resulting in equipment being washed away. Tsunami damage is sensitive to both inundation depth and flow velocity. Damage functions generated by Horspool and Fraser (2015) are used to infer damage to water treatment plants from increasing tsunami inundation depths: • < 0.5 m: Debris, likely small, deposition, salt contamination and exposed assets damage. • 0.5 - 2 m: Water contamination, equipment damaged and washed away. • > 2 m: Components washed away, structural damage.
Liquefaction	Liquefaction can be potential damaging to water treatment plants. Damage is characterised using Tonkin + Taylor expertise and observations following the Christchurch Earthquake Sequence as there is little documented damage at this stage for

	lifelines and infrastructure. For the purposes of this, it is assumed a shaking level that would induce liquefaction has occurred. Damage characterisation shows expected damage to water treatment plants from increasing levels of liquefaction land damage categories (defined by Tonkin + Taylor, 2015): • None to Minor: Oscillation damage. • Minor to Moderate: Punching into the ground up to 200 mm, potential subsequent flooding, tilting typically < 100 mm over footprint, surface cracking. • Moderate to Severe: Punching into the ground up to 1 m, potential subsequent flooding, tilting, stretching of components (external yard), surface cracking and ejecta.

3.2 Pump stations

Hazard	Damage discussion
Volcanic ash	Pump stations are susceptible to a range of impacts from increasing volcanic ashfall thickness. At small thicknesses, impacts are likely to be clogging and abrasion ranging up to collapse of structures (Wilson et al., 2014). Differences in the impacts can arise due to the chemical composition causing corrosion as well as weather, as rain causes sedimentation on components. Restoration times are based on the degree of damage as well as the amount of time required to restore services. Damage functions generated by Wilson et al (2017) are used to infer damage to pump stations from increasing tsunami inundation depths: • 5 - 20 mm: Clogging of exposed filters and possible abrasion of moving components and gully trap ingress. • 20 - 100 mm: Contamination of facility and damage to exposed pumping equipment. • > 100 mm: Irreparable damage to moving parts, structural damage to equipment.
Flooding	Flood events can inundate exposed pump stations resulting in damage ranging from silt deposition requiring clean up through to collapse of the housing structures and equipment being washed away. Flood damage is sensitive to both the flood depth and flood flow velocity. However, most damage models use flood depth as a metric indicating variability in the potential damages. Damage functions generated by Reese and Ramsay (2009) are used to infer damage to pump stations from increasing flood depths: • < 0.5 m: Debris deposition and exposed asset damage e.g. motors. • 0.5 – 2 m: Debris deposition, small impact damage and structural damage. • > 2 m: Structural damage, impact damage, damage to the housing structures, scouring of the land and even assets being washed away. Discussion with network providers found the main contributing factor to outage would be with damage to electronic components, especially at the lower depths.
Tsunami	Tsunamis can result in significant damage and outage times for pump stations. At small inundation depths, tsunamis brings with it debris and silt deposition requiring clean up through to deeper inundation depths resulting in equipment being washed away. Tsunami damage is sensitive to both inundation depth and flow velocity. Tsunamis can bring with them debris from offshore and near the coast, and high velocities can support large pieces of debris, which can severely impact assets. Damage functions generated by Horspool and Fraser (2015) are used to infer damage to pump stations from increasing tsunami inundation depths:

	• < 0.5 m: Debris, likely small, deposition, salt contamination and exposed assets damage. • 0.5 - 2 m: Water contamination, equipment damaged and washed away. • > 2 m: Components washed away, structural damage.
Liquefaction	Liquefaction can be potential damaging to pump stations. It is assumed pump station held in underground cavity. Damage is characterised using Tonkin + Taylor expertise and observations following the Christchurch Earthquake Sequence as there is little documented damage at this stage for lifelines and infrastructure. For the purposes of this, it is assumed a shaking level that would induce liquefaction has occurred. Damage characterisation shows expected damage to pump stations from increasing levels of liquefaction land damage categories (defined by Tonkin + Taylor, 2015): • None to Minor: Oscillation damage (minor impact). • Minor to Moderate: Some uplift (dependent on the ground cavity), strain incoming pipe connections. Sediment ingress leading to increased abrasion and wear in the motors. • Moderate to Severe: Significant uplift, breakages to incoming pipe connections, flooding. Sediment ingress leading to increased abrasion and wear in the motors.

3.3 Pipes

Hazard	**Damage discussion**
Volcanic ash	Pipe damage following exposure to volcanic ashfall can vary depending on the experience thickness as well as the type of pipe. Water supply pipes are typically closed and less likely to experience damage. In contrast stormwater and wastewater are open and susceptible to ash ingress. Restoration times are based on the degree of damage as well as the amount of time required to restore services. Damage functions generated by Wilson et al (2017) are used to infer damage to pipes from increasing ash thicknesses: • 10 – 50 mm: Some clogging of pipe and sedimentation, primarily from gully trap ingress points. • 50 - 250 mm: More clogging and sedimentation, potential blockages. • > 250 mm: Widespread ingress, clogging and blockages. Discussion with network operators found damage and disruption will predominantly be due to ashfall ingress into the gully traps.
Flooding	Flooding can result in significant damage to wastewater pipes. At small inundation depths, floods brings with it debris and silt deposition requiring clean up through to deeper inundation depths resulting in equipment being washed away. Flood damage is sensitive to both inundation depth and flow velocity. There is no damage function for pipes exposed to flooding. The inundation from tsunami is likely conservative, but analogous for flooding. Damage functions generated by Horspool and Fraser (2015) and Williams (2016) are used to infer damage to pipes from increasing tsunami inundation depths: • < 0.5 m: Silt infiltration, cleaning required and reduced flow. • 0.5 - 2 m: Debris contamination of the water, scour of weak backfill and pipe fractures. • > 2 m: Land scour and pipe breakages.
Tsunami	Tsunamis can result in significant damage to wastewater pipes. At small inundation depths, tsunamis can cause minor siltation requiring clean up through to deeper inundation depths resulting in land scour and breakages. Tsunami damage is sensitive to

	both inundation depth and flow velocity. Tsunamis can bring with them debris from offshore and near the coast, and high velocities can support large pieces of debris, which can severely impact assets. Damage functions generated by Horspool and Fraser (2015) and Williams (2016) are used to infer damage to pipes from increasing tsunami inundation depths: • 0.5 - 2 m: Debris contamination of the water, scour of weak backfill and pipe fractures. • > 2 m: Land scour and pipe breakages.
Liquefaction	Liquefaction can be potential damaging to wastewater pipes. Damage is characterised using Tonkin + Taylor expertise and observations following the Christchurch Earthquake Sequence as there is little documented damage at this stage for lifelines and infrastructure. For the purposes of this, it is assumed a shaking level that would induce liquefaction has occurred. Damage characterisation shows expected damage to three waters pipes from increasing levels of liquefaction land damage categories (defined by Tonkin + Taylor, 2015): • None to Minor: Oscillation damage (impact small), controlled by Peak Ground Velocity (PGV): lower (0.1 break/km); higher (1 break/km). PVC approximately a factor of 10 less than AC and CI. • Minor to Moderate: 5 to 20 times increase of pipe break of none to minor, PVC lower end of range, AC at the high end of range. Differential settlement and potential reductions in pipe gradients. Some ingress of sediment into pipes. • Moderate to Severe: 10 to 50 times increase of pipe break of none to minor, PVC lower end of range, AC at the high end of range. Differential settlement and change in pipe gradient impacts. Significant ingress of sediment into pipes.

4 Roads

Below we summarise literature relating to the main types of *damage* which may occur for roads from the various hazards. These damage descriptions were then utilised in discussion with the utility operator to estimate outage times.

Hazard	Damage discussion
Volcanic ash	Roads are susceptible to a range of impacts from increasing volcanic ashfall thickness. At small thicknesses, impacts are likely to be abrasion of road surface and markings ranging up to collapse of structures (Wilson et al., 2014). Differences in the impacts can increase as well as weather, as rain causes sedimentation and increasing loading. Restoration times are based on the degree of damage as well as the amount of time required to restore services. Damage functions generated by Wilson et al (2017) is used to infer damage to roads from increasing ashfall thicknesses: • 2 - 50 mm: Clean-up, reduced vision and mild abrasion of road markings and paved surfaces. • 50 - 150 mm: Increased abrasion to markings and paved stones. • > 150 mm: In passable roads, structural damage to bridges and supports due to loading.
Flooding	Floods can produce a range of impacts to roads from increasing flood depths. At shallow inundation depths, impacts are likely to be abrasion of road surface and markings ranging up to collapse of structures. Flood damage is sensitive to both inundation depth and flow velocity. Restoration times are based on the degree of damage as well as the amount of time required to restore services. Damage functions shown in Huizinga et al (2017) are used to infer damage to roads from increasing flood inundation depths: • < 0.5 m: Silt and debris cover, surface ponding, superficial debris strikes to structures, lights and barriers lift. • 0.5 – 2 m: Debris cover, scour of weak base materials, impact damage and removal of signage and barriers. • > 2 m: Scour of base material, lifting of surface material, debris coverage and signage, barriers and lights washed away.
Tsunami	Tsunamis can produce a range of impacts to roads from increasing inundation depths. At shallow inundation depths, impacts are likely to be abrasion of road surface and markings ranging up to collapse of structures. Tsunami damage is sensitive to both inundation depth and flow velocity. Tsunamis can bring with them debris from offshore and near the coast, and high velocities can support large pieces of debris, which can severely impact assets. Restoration times are based on the degree of damage as well as the amount of time required to restore services. Damage functions generated by Horspool and Fraser (2015) and descriptors by Williams (2016) are used to infer damage to roads from increasing tsunami inundation depths: • < 0.5 m: Silt and debris cover, surface ponding, superficial debris strikes to structures, lights and barriers lift. • 0.5 – 2 m: Debris cover, scour of weak base materials, removal of signage and barriers. • > 2 m: Scour of base material, lifting of surface material, debris coverage and signage, barriers and lights washed away.

Liquefaction	Liquefaction can be damaging to roads. Damage is characterised using Tonkin + Taylor expertise and observations following the Christchurch Earthquake Sequence as there is little documented damage at this stage for lifelines and infrastructure. For the purposes of this, it is assumed a shaking level that would induce liquefaction has occurred. Damage characterisation shows expected damage to roads from increasing levels of liquefaction land damage categories (defined by Tonkin + Taylor, 2015): • None to Minor: Oscillation damage (impact small), Maintenance issue. No outage. • Minor to Moderate: Minor differential settlement, curb and channelling minor impact, cess pit/manhole flotation, base courses are sporadically filled with ejecta, localised tar seal lift, smaller sinkholes, compromised design life due to sediment ingress, deterioration of road surface. • Moderate to Severe: Significant differential settlement, curb and channelling impacted, cess pit/manhole flotation, base courses are filled with ejecta, tar seal lift, sinkholes large enough to sink a car.

5 Telecommunications

Below we summarise literature relating to the main types of *damage* which may occur for telecommunications assets from the various hazards. The assets include: exchange buildings, overhead and buried cables, and roadside cabinets. These damage descriptions were then utilised in discussion with the utility operator to estimate outage times.

5.1 Exchange buildings and roadside cabinets

Hazard	Damage discussion
Volcanic ash	Telecommunication infrastructure is susceptible to a range of impacts from increasing volcanic ashfall thickness. At small thicknesses the main impacts is overload of the system and potential interference through to structural damage and collapse of equipment (Wilson et al., 2014). Differences in the impacts can arise in the chemical composition (causing corrosion) as well as weather, as rain causes sedimentation on components and increased loading on lines resulting in breakages. Restoration times are related to the degree of damage as well as the amount of time required to restore services. Damage functions by Wilson et al (2017) are used to infer damage to telecommunication infrastructure from volcanic ashfall thicknesses: • 5 - 30 mm: Potential interference for transmission, ash inundation and potential sedimentation within equipment if wet. • 30 - 100 mm: Blockages and shut down of cooling systems, ingress and abrasion in equipment. • > 100 mm: Structural damage to equipment.
Flooding	Telecommunication can be impacted by flooding to different degrees at increasing flood depths. At small inundation depths, flooding can cause minor siltation requiring clean up and debris strikes through to deeper inundation depths resulting in erosion and structural damage. Flooding damage is related to both inundation depth and flow velocity. Restoration times are based on the degree of damage as well as the amount of time required to restore services. Telecommunication damage curves from flooding do not exist. Damage functions for tsunami by Horspool and Fraser (2015) and descriptors by Williams (2016) are used to infer possible damage to telecommunication infrastructure from increasing inundation depths. It is acknowledged these are conservative, however were utilised as a starting point for discussion with operators. • < 0.1 m: Flooding and minor debris strikes, sediment and water infiltration in exposed assets. • 0.1 – 0.5 m: Erosion of base supports, water and sediment damage. • 0.5 - 2 m: Erosion and tilting of supports, debris strikes, water damage to electrical components, scour of cables. • > 2 m: Structural bases eroded, weakened and potential result in collapse, washout of assets and water damage. Discussion with network operators found that roadside cabinets are elevated on concrete platforms, so internal infiltration is not likely below 0.1 m.
Tsunami	Telecommunication can be impacted by tsunami to different degrees at increasing tsunami inundation depths. At small inundation depths, tsunamis can cause minor siltation requiring clean up and debris strikes through to deeper inundation depths resulting in structural collapse and assets being washed away. Tsunami damage is sensitive to both inundation depth and flow velocity. Tsunamis can bring with them debris from offshore and near the coast, and high velocities can support large pieces of debris, which can severely impact assets.

	Restoration times are based on the degree of damage as well as the amount of time required to restore services. Damage functions by Horspool and Fraser (2015) and descriptors by Williams (2016) are used to infer damage to telecommunication infrastructure from increasing tsunami inundation depths: • < 0.1 m: Flooding and minor debris strikes, sediment and water infiltration in exposed assets. • 0.1 – 0.5 m: Erosion of base supports, water and sediment damage. • 0.5 - 2 m: Erosion and tilting of supports, debris strikes, water damage to electrical components, scour of cables. • > 2 m: Structural bases eroded, weakened and potential result in collapse, washout of assets and water damage. Discussion with network operators found that roadside cabinets are elevated on concrete platforms, so internal infiltration is not likely below 0.1 m.
Liquefaction	Liquefaction can be damaging to telecommunication infrastructure such as fibre cables, dishes and exchanges. Damage is characterised using Tonkin + Taylor expertise and observations following the Christchurch Earthquake Sequence as there is little documented damage at this stage for lifelines and infrastructure. For the purposes of this, it is assumed a shaking level that would induce liquefaction has occurred. Damage characterisation shows expected damage to telecommunications infrastructure from increasing levels of liquefaction land damage categories (defined by Tonkin + Taylor, 2015): • None to Minor: Oscillation damage. • Minor to Moderate: Punching into the ground up to 200 mm, potential subsequent flooding, tilting typically < 100 mm over footprint. • Moderate to Severe: Punching into the ground up to 1 m, potential subsequent flooding, tilting, stretching and stretching of components (external yard).

5.2 Telecommunications cables

Refer to power cable section of this Appendix.

5.3 Telecommunications cellular towers

Hazard	**Damage discussion**
Volcanic ash	Telecommunication infrastructure is susceptible to a range of impacts from increasing volcanic ashfall thickness. At small thicknesses the main impacts is overload of the system and potential interference through to structural damage and collapse of equipment (Wilson et al., 2014). Differences in the impacts can arise in the chemical composition (causing corrosion) as well as weather, as rain causes sedimentation on components and increased loading on lines resulting in breakages. Restoration times are related to the degree of damage as well as the amount of time required to restore services. Damage functions by Wilson et al (2017) are used to infer damage to telecommunication infrastructure from volcanic ashfall thicknesses: • 30 - 100 mm: Welding of material on the exterior, abrasion and damage to exposed components. • > 100 mm: Structural damage to equipment.
Tsunami	Telecommunication can be impacted by tsunami to different degrees at increasing tsunami inundation depths. At small inundation depths, tsunamis can cause minor siltation requiring clean up and debris strikes through to deeper inundation depths resulting in structural collapse and assets being washed away. Tsunami damage is sensitive to both inundation depth and flow velocity. Tsunamis can bring with them debris from offshore and near the coast, and high velocities can support large pieces of debris, which can severely impact assets. Restoration times are based on the degree of damage as well as the amount of time required to restore services. Damage functions by Horspool and Fraser (2015) and descriptors by Williams (2016) are used to infer damage to telecommunication infrastructure from increasing tsunami inundation depths: • 0.5 - 2 m: Erosion base and tilting of supports, debris strikes, water damage to electrical components. • > 2 m: Structural bases eroded, weakened and potential result in collapse, washout of assets and water damage.
Liquefaction	Liquefaction can be damaging to telecommunication infrastructure such as fibre cables, dishes and exchanges. Damage is characterised using Tonkin + Taylor expertise and observations following the Christchurch Earthquake Sequence as there is little documented damage at this stage for lifelines and infrastructure. For the purposes of this, it is assumed a shaking level that would induce liquefaction has occurred. Damage characterisation shows expected damage to telecommunications infrastructure from increasing levels of liquefaction land damage categories (defined by Tonkin + Taylor, 2015): • None to Minor: Oscillation damage. • Minor to Moderate: Punching into the ground up to 200 mm, potential subsequent flooding, tilting typically < 100 mm over footprint. • Moderate to Severe: Punching into the ground up to 1 m, potential subsequent flooding, tilting and stretching of components.

6 Gas sector

Below we summarise literature relating to the main types of *damage* which may occur for gas sector assets from the various hazards. The gas assets include: buried gas pipes, and delivery points/valves. These damage descriptions were then utilised in discussion with the utility operator to estimate outage times.

6.1 Gas pipes (buried)

Hazard	**Damage discussion**
Flooding	There is no damage function for gas pipes exposed to flooding – so damage was discussed in person with the local gas operator. Two types of pipes are utilised within the network: • Transmission lines: Steel pipes (200 mm, 75 mm, 50 mm diameters), generally buried around 1m below ground. • Distribution lines: PE pipes (20-60 mm diameters), generally buried around 600 mm below ground. It was the view of the operator (First Gas) that no damage would result from flooding on steel pipes, and for PE pipes, only scour damage may result from high velocities (under extreme flood events).
Tsunami	There is no damage function for gas pipes exposed to Tsunami – so damage was discussed in person with the local gas operator. As discussed above, there are both steel transmission, and PE distribution pipes used within the network. It was the view of the operator (First Gas) that no damage would result from tsunami on steel pipes, however for PE pipes, scour damage may result from high velocities (under moderate and extreme tsunami events).
Liquefaction	As discussed, gas pipes consist of both steel and PE materials. During discussions with First Gas, they noted that they would not expect any damage to steel pipelines from liquefaction. Their experience during the Edgecumbe earthquake was that steel pipes can absorb significant distortion and movement without breaking. For PE pipes, however damage could be expected. As such, damage was characterised using Tonkin + Taylor expertise and observations following the Christchurch Earthquake Sequence. For the purposes of this, it is assumed a shaking level that would induce liquefaction has occurred. Damage characterisation shows expected damage to three waters pipes from increasing levels of liquefaction land damage categories (defined by Tonkin + Taylor, 2015): • None to Minor: Oscillation damage (impact small). • Minor to Moderate: 5 to 20 times increase of pipe break of none to minor, PE / PVC lower end of range. • Moderate to Severe: 10 to 50 times increase of pipe break of none to minor, PE / PVC lower end of range.

6.2 Delivery points and valves

Hazard	Damage discussion
Flooding	There is no damage function for gas assets exposed to flooding – so damage was discussed in person with the local gas operator. Due to the system being sealed, damage from flood was considered very unlikely. The disruption would be from cleaning of the equipment.
Tsunami	Tsunamis could result in significant damage to gas assets (incl delivery points). At small inundation depths, tsunamis can cause minor siltation requiring clean up through to deeper inundation depths resulting in land scour and breakages. Tsunami damage is sensitive to both inundation depth and flow velocity. Tsunamis can bring with them debris from offshore and near the coast, and high velocities can support large pieces of debris, which can severely impact assets. Damage functions generated by Hatayama (2014) and Horspool and Fraser (2015) and descriptors by Williams (2016) are used to infer damage to gas storage from increasing tsunami inundation depths: • < 0.5 m: Foundation scour. • 0.1 – 0.5 m: Debris impacts, scour to foundations. • > 0.5 m: Major debris impacts, scour to foundations.
Liquefaction	Liquefaction can be potential damaging to gas assets (including delivery points). Damage is characterised using Tonkin and Taylor expertise and observations following the Christchurch Earthquake Sequence as there is little documented damage at this stage for lifelines and infrastructure. For the purposes of this, it is assumed a shaking level that would induce liquefaction has occurred. Damage characterisation shows expected damage to gas assets from increasing levels of liquefaction land damage categories (defined by Tonkin + Taylor, 2015): None to Minor: Oscillation damage (impact small). Minor to Moderate: Minor differential settlement resulting in tilting. Moderate to Severe: Significant differential settlement, broken connections.

Appendix C: Example assessment

In this Appendix we present two examples of how to apply the assessment framework presented in this report to determine a consequence level from the RPS Appendix L (Figure C1).

Consequence level	Built			Lifelines utilities
	Social/cultural	Buildings	Critical buildings	
Catastrophic	≥25% of buildings of social/cultural significance within hazard assessment area have functionality compromised.	≥50% of buildings within hazard assessment area have functionality compromised.	≥25% of critical buildings within hazard assessment area have functionality compromised.	A lifeline utility service is out for > 1 month (affecting ≥ 20% of the town/city population) OR out for > 6 months (affecting < 20% of the town/city population).
Major	11–24% of buildings of social/cultural significance within hazard assessment area have functionality compromised.	21–49% of buildings within hazard assessment area have functionality compromised.	11–24% of critical buildings within hazard assessment area have functionality compromised.	A lifeline utility service is out for 1 week – 1 month (affecting ≥ 20% of the town/city population) OR out for 6 weeks to 6 months (affecting < 20% of the town/city population).
Moderate	6–10% of buildings of social/cultural significance within hazard assessment area have functionality compromised.	11–20% of buildings within hazard assessment area have functionality compromised.	6–10% of critical buildings within hazard assessment area have functionality compromised.	A lifeline utility service is out for 1 day to 1 week (affecting ≥ 20% of the town/city population) OR out for 1 week to 6 weeks (affecting < 20% of the town/city population).
Minor	1–5% of buildings of social/cultural significance within hazard assessment area have functionality compromised.	2–10% of buildings within hazard assessment area have functionality compromised.	1–5% of critical buildings within hazard assessment area have functionality compromised.	A lifeline utility service is out for 2 hours to 1 day (affecting ≥ 20% of the town/city population) OR out for 1 day to 1 week (affecting < 20% of the town/city population).
Insignificant	No buildings of social/cultural significance within hazard assessment area have functionality compromised.	<1% of buildings within hazard assessment area have functionality compromised.	No damage within hazard assessment area, fully functional.	A lifeline utility service is out for up to 2 hours (affecting ≥ 20% of the town/city population) OR out for up to 1 day (affecting < 20% of the town/city population).

Figure C1: Consequence table (from RPS, Appendix L)

Two different asset types are presented as examples, both from the wastewater sector; a **treatment facility** and a **150 mm wastewater pipe**. The example hazard is **flooding.**

These two selected asset examples will be discussed with reference to the four step process presented in this report and shown below in Figure C2 to determine a consequence level for each.

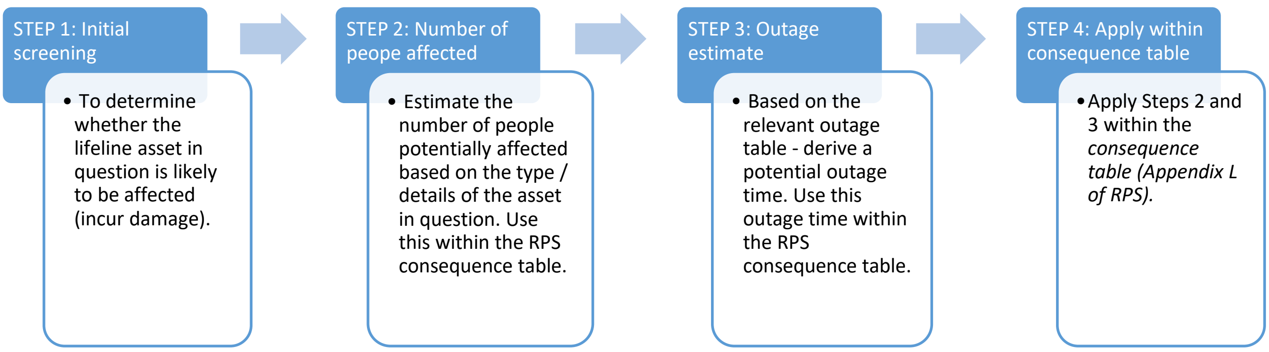

Figure C2: Four step process to undertake lifelines consequence assessment for RPS

1 Step 1: Initial screening

The first step is to assess if the asset is susceptible to damage by the hazardous event, regardless of hazard intensity. This then determines whether the remaining steps are needed. Refer to Table C1.

Table C1: Flood hazard example assessing whether an asset type is susceptible to damage. Red box indicates the wastewater treatment plant, yellow for wastewater pipe

	Flooding	Tsunami	Volcanic ash	Liquefaction
Power				
Power substations	1	1	1	1
Power transmission and distribution lines - overhead on poles	1	1	1	1
Power transmission and distribution lines - overhead on pylons	1	1	1	1
Power transmission and distribution lines - buried	1	1	0	1
Power generation sites	1	1	1	1
Water supply				
Treatment plants	1	1	1	1
Pump stations	1	1	1	1
Reservoirs	0	0	1	1
Pipes	1	1	0	1
Groundwater intakes	1	1	1	1
Surface water intakes	1	1	1	1
Wastewater				
Treatment plants	1	1	1	1
Pump stations	1	1	1	1
Pipes	1	1	1	1
Road transportation				
Roads	1	1	1	1
Telecommunications				
Exchanges	1	1	1	1
Overhead cables	0	1	1	1
Buried cables	1	1	0	1
Roadside cabinets	1	1	1	1
Cell towers	0	1	1	1
Gas				
Pipes	1	1	0	1
Delivery points and valves	1	1	0	1

1	Affected
0	Unaffected

As shown, both wastewater treatment plants and wastewater pipes are susceptible to flood damage, and therefore are required to be assessed to determine a consequence level from flood hazard. This means progressing to step 2, 3 and 4.

2 Step 2: Assess number of people affected

As part of establishing a consequence level, there is a need to understand the proportion of the population potentially effected by an outage of the asset. As discussed in the Section 3.2, there are two ways to assess the proportion of the population affected. In the absence of a case-specific assessment, a generalised approach is taken, utilising Table C2.

Table C2: Selection of the appropriate criticality for asset types represented by affected population for the examples. Red box is for the wastewater treatment plant, yellow for wastewater pipes.

Asset type	< 20% population percentage	> 20% population percentage
Power		
Power substations	-	All substations
Power transmission and distribution lines - overhead on poles	Distribution lines	Transmission lines
Power transmission and distribution lines - buried	Distribution lines	Transmission lines
Power transmission lines - overhead on pylons	-	Transmission lines
Power generation sites	-	All generation sites
Water supply		
Treatment plants	-	All treatment plants
Pump stations	-	All pump stations
Reservoirs	-	All reservoirs
Pipes	Diameter ≤ 100 mm	Diameter > 100 mm
Groundwater intakes	-	All groundwater intakes
Surface water intakes	-	All surface water intakes
Wastewater		
Treatment plants	-	All treatment plants
Pump stations	-	All pump stations
Pipes	Diameter ≤ 150 mm	Diameter > 150 mm
Road transportation		
Roads	Access or collector road (ONRC)	Arterial, regional, or national road (ONRC)
Telecommunications		
Exchanges	-	All exchanges
Overhead cables	All overhead cables	-
Buried cables	Network fibre or ≤ 1000 pair distribution	Core fibre or > 1000 pair network
Roadside cabinets	Al roadside cabinets	-
Cell towers	All cell towers	-
Gas		
Pipes	PVC pipes	Steel pipes
Delivery points and valves	-	All delivery points and valves

As shown above, a wastewater treatment plant outage is deemed to affect greater than 20% of a population. Wastewater pipes are dependent on pipe diameter. If the pipe is ≤ 150 mm in diameter, it is deemed that less than 20% will be affected, and vice versa.

3 Step 3: Estimate outage time

Step 3 of the consequence assessment is to determine the duration of outage for the asset, based on a given hazard magnitude/ intensity.

An important input into this part of the assessment is the hazard magnitude. Appendix L of the RPS stipulates the required Annual Exceedance Probability (AEP) events for different hazards, and as is shown below, a flooding assessment required a 1% AEP for 'initial' analysis, and potentially a 2% and 0.2% AEP event for 'secondary' analysis. The relevant hazard analysis will need to be sourced or generated, along with corresponding flood **depths** which are then used as discussed below.

Table C3: BOPRC RPS Appendix L, Likelihoods for risk assessment (Table 20)

Hazard	Column A: Likelihood for initial analysis[+] AEP (%)[#]	Column B: Likelihood for secondary analysis[+] AEP (%)[#]
Volcanic hazards (including geothermal)	0.1	0.2 0.005
Earthquake (Liquefaction)	0.1	0.2 0.033
Earthquakes (Fault rupture)	0.017	0.2 0.005
Tsunami	0.1	0.2 0.04
Coastal erosion	1	2 0.2
Landslip (Rainfall related)	1	2 0.2
Landslip (Seismic related)	0.1	0.2 0.033
Flooding (including coastal inundation)	1	2 0.2

Once the hazard depths for the relevant AEP events are sourced / generated the depths are then used within the outage look up tables. Below are the respective look-up tables for assessing wastewater treatment plants and pipes for flood hazards. For the purposes of this example, we will assume that the **estimated flood depth is 1.0 m.**

Table C4: Selection of the appropriate outage duration for wastewater treatment plant from a 1m flood depth, highlighted by the red box.

	Hours	Days	Weeks	Months	> 6 months
Flood (Depth)					
< 0.5 m					
0.5 - 2 m					
> 2 m					

Table C5: Selection of the appropriate outage duration for wastewater pipes from a 1 m flood depth, highlighted by the red box.

	Hours	Days	Weeks	Months	> 6 months
Flood (Depth)					
< 0.5 m	No impact or disruption expected				
0.5 - 2 m					
> 2 m					

As shown, the expected outage for wastewater treatment plants is in the **weeks** durations, and wastewater pipes in the **days** duration, from a 1 m flood.

4 Step 4: Determine consequence level

When determining a consequence level for asset types, it requires combining an understanding of the population proportion (step 2) with the expected outage duration (step 3). Below is the RPS table presenting both the wastewater treatment plants and pipes outage, from a 1 m flood hazard.

Consequence level	Built			Lifelines utilities
	Social/cultural	Buildings	Critical buildings	
Catastrophic	≥25% of buildings of social/cultural significance within hazard assessment area have functionality compromised.	≥50% of buildings within hazard assessment area have functionality compromised.	≥25% of critical buildings within hazard assessment area have functionality compromised.	A lifeline utility service is out for > 1 month (affecting ≥ 20% of the town/city population) OR out for > 6 months (affecting < 20% of the town/city population).
Major	11–24% of buildings of social/cultural significance within hazard assessment area have functionality compromised.	21–49% of buildings within hazard assessment area have functionality compromised.	11–24% of critical buildings within hazard assessment area have functionality compromised.	A lifeline utility service is out for 1 week – 1 month (affecting ≥ 20% of the town/city population) OR out for 6 weeks to 6 months (affecting < 20% of the town/city population).
Moderate	6–10% of buildings of social/cultural significance within hazard assessment area have functionality compromised.	11–20% of buildings within hazard assessment area have functionality compromised.	6–10% of critical buildings within hazard assessment area have functionality compromised.	A lifeline utility service is out for 1 day to 1 week (affecting ≥ 20% of the town/city population) OR out for 1 week to 6 weeks (affecting < 20% of the town/city population).
Minor	1–5% of buildings of social/cultural significance within hazard assessment area have functionality compromised.	2–10% of buildings within hazard assessment area have functionality compromised.	1–5% of critical buildings within hazard assessment area have functionality compromised.	A lifeline utility service is out for 2 hours to 1 day (affecting ≥ 20% of the town/city population) OR out for 1 day to 1 week (affecting < 20% of the town/city population).
Insignificant	No buildings of social/cultural significance within hazard assessment area have functionality compromised.	<1% of buildings within hazard assessment area have functionality compromised.	No damage within hazard assessment area, fully functional.	A lifeline utility service is out for up to 2 hours (affecting ≥ 20% of the town/city population) OR out for up to 1 day (affecting < 20% of the town/city population).

Figure C3: Consequence table (from RPS, Appendix L). Output consequence level for wastewater treatment plant is shown in the red box. Output consequence level for 150mm wastewater pipe is shown in yellow.

The outage for a wastewater treatment plant is likely to affect more than 20% of the population of the region, and for a 1 m flood hazard depth, will result in an expected outage duration in the order of weeks. As presented above, this results in a consequence level of **'major'** for the wastewater treatment plant in this example.

The outage for a 150 mm wastewater pipe will likely affect less than 20% of the population. For a 1 m flood depth, the outage duration is expected to be in the days timeframe. Through combining these, the consequence level is assessed as '**minor'**.

This lifeline consequence assessment can then be used to generate an overall *consequence level* score (insignificant to catastrophic – see Figure C3) and then paired with the *hazard likelihood* to evaluate the level of risk. This risk assessment process is set out in the RPS Appendix L.

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