

## Natural Hazards Risk Associated with Petroleum Storage in the Wellington Region, New Zealand

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**ABSTRACT:** Wellington Regional Council has a strategy to identify, assess and manage the risks from natural and technological hazards. As part of this strategy a study was carried out to assess the risks associated with petroleum storage from natural hazards. The predominant hazard posing a risk to petroleum storage facilities in the Wellington Region is earthquakes. The assessment included bulk petroleum storage facilities, storage at service stations as well as pipelines.

This case study illustrates the assessment of the risk associated with spill and fire / explosion events at petroleum storage facilities, due to natural hazards, using techniques such as event and fault tree analyses. The vulnerability of the tanks was assessed based on their age, condition, design characteristics and the earthquake hazards. The earthquake hazards included ground shaking, liquefaction and slope failures, and other natural hazards comprised wild fire, flooding and storm induced landslides.

The effect of petroleum spills or fire / explosion were assessed considering the people, built and natural environments. The risks to these environments were assessed as a combination of the hazard and the vulnerability of these environments to the consequences. The spatial risk was derived using a geographical information system.

Risk management measures were identified to manage the risks from the hazards associated with petroleum storage.

### 1 INTRODUCTION

Wellington Regional Council has an aim to achieve an acceptable level of risk in the Wellington Region of New Zealand. The risk arises from a variety of hazards, such as earthquakes, storms, flooding, wild fire and lightning (natural hazards), as well as technological hazards such as from petroleum and other hazardous substances. The Council is pursuing a proactive strategy to ensure that the community is prepared, and where appropriate, risk management measures are in place. As part of this strategy, a study of the natural hazards risk associated with storage of petroleum in the Region was carried out by Opus International Consultants (2000), for the Wellington Regional Council.

The objective is to determine the nature and spatial distribution of bulk storage of petroleum in the Wellington Region, and the risk associated with such storage, from natural hazards.

Wellington Region has a high risk from natural hazards, particularly earthquakes, but also other significant ones such as flooding, storms and wild fire. While no major natural hazard event has affected petroleum storage in the Region, there is a potential risk to the people as well as the built and natural environments.

## 2 METHODOLOGY

A methodology was developed to achieve the desired objectives of a regional assessment of the risk within the time and financial constraints of the study. The method comprised a review of the literature on the impact of natural hazards on petroleum facilities, collection of data on the location and quantities of bulk storage and on the people, built and natural environments, discussion with petroleum companies, review of natural hazards data, assessment of the vulnerability of the storage facilities, assessment of petroleum spill and explosion hazards, derivation of the risk using a geographical information system and presentation of the results. Discussions were held with emergency services and typical response plans were reviewed. Potential risk management measures were identified.

## 3 TANK DESIGN STANDARDS AND CODES OF PRACTICE

The design standard commonly used for the design of petroleum storage facilities in the USA is API 650 (American Petroleum Institute, 1991), and this standard is also commonly used elsewhere by US based petroleum companies. It is understood that this standard was used for upgrading the tank farms in the Wellington Region. Therefore, observation of tank damage in overseas earthquakes provided a useful basis for assessing the potential for damage to petroleum tanks in this study. In New Zealand, guidance on seismic design is provided in the publication, Seismic Design of Petroleum Tanks (Ministry of Works & Development, 1981), and this is used in conjunction with API 650.

## 4 PERFORMANCE OF TANKS IN PAST EARTHQUAKES

Extensive tank damage occurred at the Bay Milk Products dairy factory in the 1987 Edgecumbe Earthquake (Pender and Robertson, 1987), through different mechanisms such as failure of holding down bolts, sliding and toppling. However, these tanks were more vulnerable than the petroleum tanks considered in this study, due to the thin wall construction and the lower diameter to height ratios of the milk tanks, which increased their propensity for damage and toppling in an earthquake.

The US National Institute of Standards and Technology (NIST) commissioned a study (Cooper, 1997) following the extensive damage to petroleum tanks in the 1994 Northridge Earthquake in California, and this presents the performance of storage tanks during major earthquakes between 1933 and 1995. Typical damage to tanks is documented as:

- elephant foot buckling, which is significant wall deformation leading to buckling near the base;
- rupture of the pipe/tank interface;
- roof damage associated with the sloshing of the fluid inside the tank; and
- uplifting of the tanks leading to collapse.

No significant information was identified on damage to petroleum storage tanks from storms or flooding, probably as such damage is generally not frequent or significant.

A recent large petroleum tank fire was caused by a lightning strike that occurred in July 1996 in Ontario, and the fire only involved an approximately 20,000 m<sup>3</sup> floating roof gasoline tank. A more spectacular event took place in September 1924 in Monterey, California where an 8,000 m<sup>3</sup> floating roof crude oil tank was ignited by a lightning strike. This fire, by radiation, ignited other fuel tanks explosively, leading to spillage of burning fuel flowing into the bay and threatening the wharf area.

## 5 VULNERABILITY OF TANKS TO EARTHQUAKE DAMAGE

Observations of damage from past earthquakes indicate earthquake damage to tanks to be dependent on a number of tank characteristics summarised below.

- (a) The risk of tank failure increases with diameter to height (D/H) ratios. Tanks with ratios of 2 and above tend not to have elephant foot buckling and therefore have a lower propensity for failure.

- (b) Failure is prevalent at pipe/tank connections. It is important to have flexibility at these joints to reduce the likelihood of damage.
- (c) Cone roof tanks with fragile roof/shell joints and large D/H ratios have suffered failure at roof/shell joints with the consequent spillage of the product.
- (d) Roof/shell damage to cone roof tanks has been evident in many earthquakes.
- (e) There is a higher likelihood of failure at the pipe/shell joint if the pipe is connected through the bottom shell of the tank.
- (f) The quantity of fluid in the tanks at the time of the earthquake is a factor in determining the level of damage. Generally, the higher the level of fluid, the more likely it is that damage will occur.

Local soil conditions have a major influence on the performance, with a higher vulnerability, where soils are susceptible to liquefaction and consequential lateral spreading or ground deformation. Underground storage tanks are generally reasonably resistant to damage from earthquake ground shaking alone because they are buried in the ground. However, they are particularly vulnerable to liquefaction, where they can also float out of the ground due to increased buoyancy in liquefied soil.

## 6 CLASSIFICATION OF STORAGE SITES AND PRODUCTS

### 6.1 Classification of storage sites

Four classes of petroleum storage sites were identified in the Region, the classification being based on the data collected and site reconnaissance of representative major petroleum storage sites. These are:

- (a) Major bulk storage tanks at Seaview (tank farms), Kaiwharawhara, Miramar and Burnham Wharf
- (b) Intermediate bulk storage tanks at Seaview (excluding tank farms), service stations and airports.
- (c) Small storage sites in buildings and miscellaneous locations, generally less than 40,000 litres.
- (d) Pipelines from Kaiwharawhara to Aotea Quay and Point Howard to Seaview.

The locations of all major, intermediate and known small storage sites were mapped into an ArcView geographical information system (GIS) database. The data on small storage sites is not complete. However, they only pose a limited risk from a regional perspective, and were not assessed in detail.

### 6.2 Classification of petroleum products

Four broad categories of petroleum products are stored in the region, with the classification based on product data sheets and the identified hazards such as fire / explosion, toxicity, mobility, persistence, bio-accumulation and aquatic toxicity. The categories are summarised in Table 1, which also identifies a representative product in each group that was used in the detailed hazard assessment.

**Table 1. Petroleum product classification**

Group	Representative Product	Other Products Covered
I	Liquefied Petroleum Gas (LPG)	-
II	Petrol	Aviation Gas
III	Diesel	Jet Fuel, Kerosene, Light Fuel Oil (LFO)
IV	Lubricants	Waste Oil, Bitumen

## 7 NATURAL HAZARDS

### 7.1 Earthquakes

Wellington Region is in one of the most seismically active areas of New Zealand. Earthquakes can lead to ground shaking, liquefaction, slope failures, fault rupture, tsunami / seiche and land

subsidence. Fault rupture could cause severe damage to storage facilities along the Wellington Fault and within close proximity. Scientists consider that subsidence of land in the lower coastal areas of the Hutt Valley (such as Seaview) could occur during a Wellington Fault earthquake. Given that the Seaview tank farms are more than 1 m higher than the sea level, subsidence is unlikely to bring them below sea level. However, subsidence could cause difficulties in the operation of the facilities.

The Seaview tank farms are located in areas underlain by deep marine sediments and reclamation fill. The sites have generally been upgraded in the last 15 years to reduce the risk of liquefaction in small to moderate earthquakes. However, amplified ground shaking, some liquefaction and limited ground deformation are likely in large earthquakes. The Kaiwharawhara storage tanks are located adjacent to steep slopes and earthquake induced slope failures could cause damage to these tanks.

**7.2 Other hazards**

Natural hazards other than earthquakes were considered in the assessment, and include:

- Storms – slope failures, flooding and wind, are likely to particularly affect the pipelines between Kaiwharawhara and Aotea Quay.
- Tsunami / seiche
- Wild fire – originating from vegetated hillsides adjacent to storage facilities. Bulk storage tanks and LPG tanks may be particularly vulnerable. Some tanks are located near scrub vegetation areas of extreme or very high risk of wild fire (Wellington Regional Council, 1998).
- Exposure fires
- Lightning

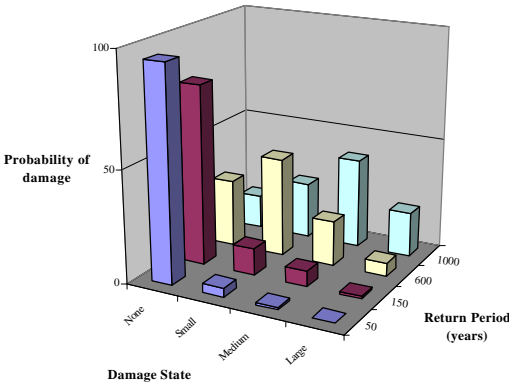
**8 PETROLEUM RELEASE ASSESSMENT**

The likelihood of petroleum release leading to spill, fire or explosion is dependent on the structural performance of the storage tanks, when subject to natural hazards. Damage models were developed for each of the main types of storage facilities based on observed past performance, the HAZUS models (National Institute of Building Sciences, 1997), the design standards for the tanks, the ground conditions, and visual inspection of the storage facilities. The likely size of the release was important to assess the consequences and hence the risk, and the models were modified to relate the damage state to the likely size of release of the contents from the tanks.

The release sizes considered in the assessment are:

- Small (5,000 to 50,000 litres) damage to tank resulting in minor leakage
- Medium (50,000 to 500,000 litres) failure of small to medium size tank, with loss of contents
- Large (greater than 500,000 litres) failure of large tank or multiple tanks with loss of contents

As an example, the likely probabilities of petroleum spill from earthquakes for the major bulk storage tanks in Seaview are presented in Figure 1.



**Figure 1. Petroleum spill model for the major Seaview bulk storage tanks**

## 9 HAZARD ASSESSMENT

### 9.1 Likelihood of release

The likelihood of release from all natural hazards was assessed using fault tree analyses, with inputs based on available information, parameters reported in the literature and the subjectively assessed performance. The following two types of hazards were assessed using fault tree analyses:

- Petroleum spill / release
- Fire / explosion consequences

A typical fault tree is presented in Figure 2. An annual probability of petroleum release for various sizes of release for each class of petroleum storage facility was derived from the fault trees.

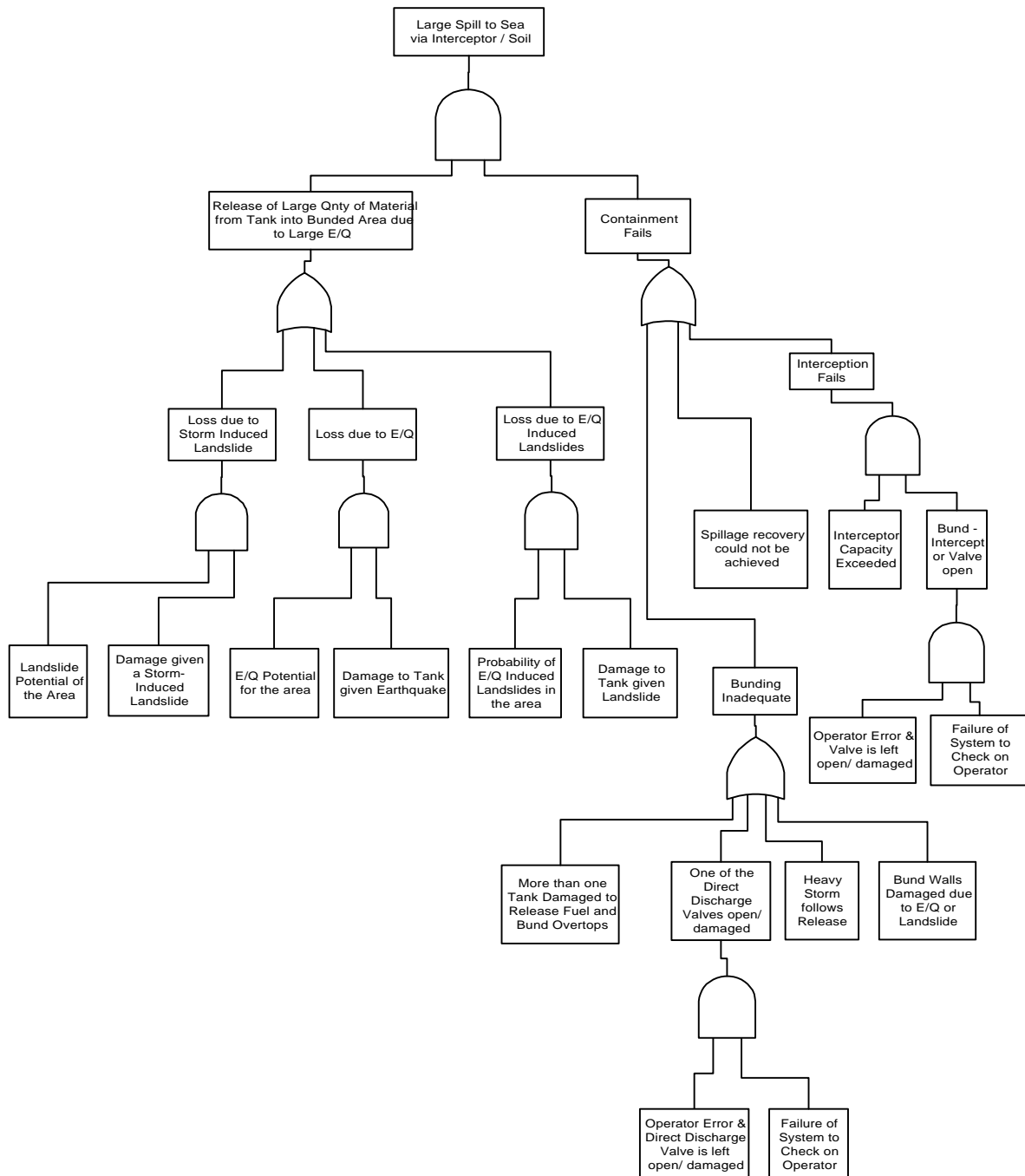


Figure 2. Generic fault tree for spills from tank due to natural hazards

## 9.2 Petroleum release hazard

The relative petroleum release hazards for the different classes of petroleum storage facilities in the Region are indicated by the hazard ratings presented in Table 2. The hazard rating was derived as :

$$\text{Hazard Rating} = \text{Size of large release} \times \text{annual probability of release}$$

Different sizes of release likely from different classes of facilities were taken into consideration for the various classes of petroleum storage facilities.

The presence of LPG enhances the hazard to people and the built environment, given its much severe impact, due to its susceptibility to cause explosions. However, it will have lesser impact on the natural environment as it does not have persistent long-term effects. The hazard rating for service stations where LPG is stored (there are no bulk storage facilities for LPG in the Wellington Region) was modified to reflect the increased hazard from LPG to the people and the built environment. The modified hazard rating to reflect the increased hazard was derived as:

$$\text{Hazard Rating} = (\text{Size of large non LPG release} \times \text{annual non-LPG probability of release}) + (\text{Size of LPG release} \times \text{annual probability of LPG release} \times 3)$$

Conversely diesel poses a lesser hazard to people and the built environment, but a more severe effect on the natural environment due to its long-term persistence.

**Table 2. Hazard ratings for petroleum release**

<b>Class of Petroleum Facility</b>	<b>Hazard Rating</b>
Major Tank Farms, Seaview	240
Bulk Storage Tanks, Seaview	31
Bulk Storage Tanks, Miramar	15
Bulk Storage Tanks, Kaiwharawhara	235
Single Tanks	42
Mainline Pipes	49 to 574
Service Stations	1 to 50

The higher hazard ratings for the Kaiwharawhara bulk storage tanks and the pipeline represent their vulnerability to landslides and floods from storms that have a higher probability than earthquakes.

## 9.3 Petroleum fire / explosion hazard

Petroleum fires can result from ignition of spills, wild fires and lightning. These fires predominantly affect above ground storage, and under severe conditions explosions may also occur.

## 10 RISK

The risk associated with petroleum storage was assessed as a combination of the hazard and the consequences, consistent with the approach recommended in the Australia / New Zealand Standard AS/NZS 4360:1999 (Standards Australia, 1999).

The consequences are different for the people, built and natural environments, and were considered separately. The vulnerabilities of these receptors were represented by subjective ratings assigned depending on the population density (persons per square km), the land use (rural, residential or commercial /industrial) and the sensitiveness of the natural environment (low, medium and high).

The combined risk for all three environments was derived as below and assigned subjective risk descriptions from very low to very high:

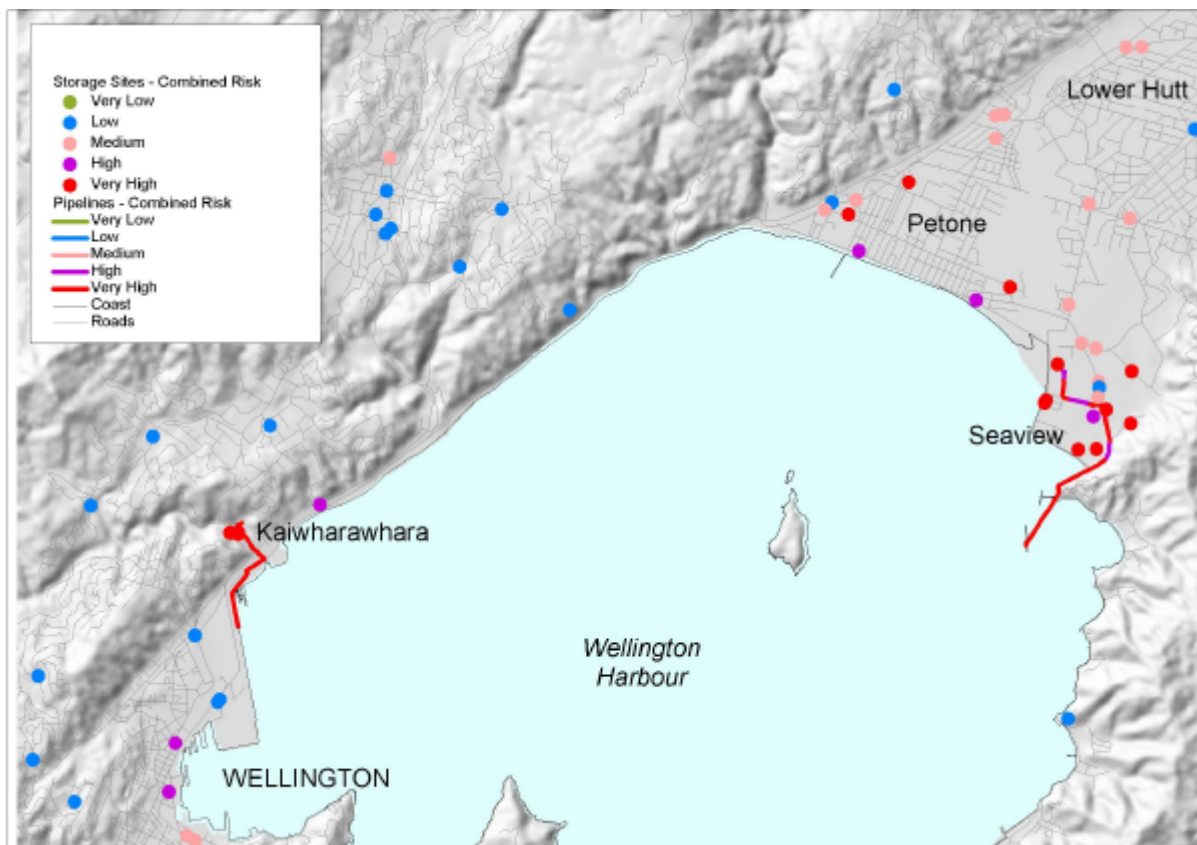
$$\text{Combined Risk} = (\text{People Risk} \times W_P) + (\text{Built Environment Risk} \times W_{BE}) + (\text{Natural Environment Risk} \times W_{NE})$$

where  $W_P$ ,  $W_{BE}$  and  $W_{NE}$  are weightings for the people, built and natural environments respectively, and the individual risks to the different environments are :

$$\begin{aligned} \text{People Risk} &= \text{Hazard Rating} \times \text{People Vulnerability Rating} \\ \text{Built Environment Risk} &= \text{Hazard Rating} \times \text{Built Environment Vulnerability Rating} \\ \text{Natural Environment Risk} &= \text{Hazard Rating} \times \text{Natural Environment Vulnerability Rating} \end{aligned}$$

The natural environment risk assumed that petroleum spills within 150 m of high vulnerability environments such as harbours and rivers can affect them. Also sensitive environments such as water bodies can be affected by spills from major storage facilities within their immediate catchments, even when located greater than 150 m away.

A section of the combined risk map is shown on Figure 3. These spatial risk maps were derived with the aid of an ArcView geographical information system. The people, built and natural environment vulnerabilities, and the locations and hazard ratings for each petroleum storage facility in the region, were mapped in the spatial database, and estimates of risk were derived from the spatial information.



**Figure 3. Combined risk map for part of the Wellington Region**

Table 3 presents the risk of fatalities from a petroleum storage fire in the Wellington Region in comparison with other commonly known risk events (Higson, 1989) for Australia. It can be seen that the chance of fatalities from a petroleum storage fire from natural hazards is relatively low.

**Table 3. Comparison of Annual probabilities of various involuntary risks**

<b>Activity with Risk</b>	<b>Chances of Fatality per million person years</b>
Motor Vehicle Travel	145
Aeroplane Flight	10
Electrocution (non-industrial)	3
Cataclysmic Storms and Floods	0.2
Lightning Strike	0.1
<b>Petroleum Storage Fire in the Wellington Region</b>	<b>0.05</b>
Meteorite Impact	0.001

## 11 RISK MANAGEMENT

The risks associated with petroleum storage can be reduced by a number of approaches, such as reducing the likelihood of an incident, through safety and emergency shut-down facilities, re-routing or burying pipelines, improved maintenance of the storage tanks or pipelines, upgrading facilities not designed for hazards such as earthquakes, and relocating tanks to lower hazard areas in the long term. These measures can be used appropriately to reduce the risk associated with different storage facilities.

The consequences of an incident (and hence the risk) could also be reduced by providing or upgrading existing bunds to prevent escape of petroleum and incorporating fire fighting features where absent.

Land use planning and consents could be used to reduce the risk from incidents, by maintaining or enhancing a separation between hazardous facilities and the vulnerable environments such as people.

Emergency management could be improved. Recent developments of adopting the New Zealand Coordinated Incident Management System (CIMS) by all parties and the setting up of Civil Defence Emergency Management (CDEM) groups would help better plan emergency management responses.

## 12 CONCLUSIONS

Risks associated with petroleum storage from natural hazards have been assessed as part of a strategy to achieve an acceptable level of risk from natural / technological hazards in the Wellington Region. The study has highlighted the higher risks associated with the tank farms in Seaview, given their size, location vulnerable to earthquake hazards and their proximity to the harbour, although they have been generally well-built. It also highlighted elevated risks posed by the tanks in Kaiwharwhara and the pipeline between Kaiwharwhara and Aotea Quay, due to their exposure to multiple hazards including floods, earthquake, landslide and storms. Some LPG tanks at service stations also pose a notable risk

The annual probabilities of fatalities from petroleum fire in the Wellington Region are generally lower compared to other involuntary hazards faced by the community.

Risk management measures can help reduce the risk and these are identified and presented. Given the lower frequency higher impact nature of these hazards, emergency management is one of the primary means of risk management, particularly where the risks are difficult to mitigate.

The methodology developed and used in this study made use of GIS to help assess spatially distributed risks, in an effective and efficient manner. The subjective nature of aspects of this risk assessment is acknowledged, and is considered prudent for this regional scale assessment.

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