Auckland Regional Council
TE RAUHITANGA TAIAO

Risk posed by a hazardous substance release due to an earthquake or flooding in the Auckland region

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Peer Reviewed by Suzie Wood

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Executive Summary

Hazardous substances are commonly stored throughout the Auckland Region and may include explosive, flammable, oxidising, toxic, corrosive or ecotoxic gasses, liquids or solids. Although a number of events may lead to hazardous substance release from storage facilities this report looks specifically at the risk posed to the population of the Auckland Region by the release of hazardous substances due to an earthquake or flooding. In addition, this report identifies economic elements, response and recovery facilities and significant natural environments in close proximity to stored hazardous substances.

Aims

This report aims to:

- Identify hazardous facilities presenting significant risks resulting from accidental hazardous substance release during either an earthquake or flooding;
- Identify gaps in available information; and
- Recommend potential uses and development of this database.

Methodology

This study uses spatial distribution and semi-quantitative methods to assess risk. Specifically this study looks at risk posed to life (population density), economy (employment density, dwelling density), emergency response and recovery elements (priority routes, schools, emergency services), and the environment (significant natural environments) due to hazardous substance release resulting from an earthquake or flood event. This study only addressed earthquake and flooding hazards because these are the only two hazards that have been adequately analysed for their spatial variation in risk.

Historically there has been no overarching legislation relating to hazardous substances and therefore data collection is often fragmentary and incomplete. This study collected hazardous substance information from a number of different sources and addressed only those substances stored above a low threshold, allowing assessment of the cumulative effects of several small releases. The dangerous goods databases held by TAs proved to be the most useful and complete record, however, the quality of data varied considerably between TAs. The Occupational Safety and Health (OSH) Explosive Storage Licences also proved a useful source of information.

Results

77% of hazardous substances are located in areas prone to earthquake and flooding hazards. Those associated with high population density and high hazard ratios are located in Auckland City. Those that have a high hazard ratio and high employment and dwelling densities are in Auckland City, Manukau City and Waitakere City. These substances are stored mainly in areas prone to earthquake-induced hazards.

45% of hazardous substances stored in areas prone to hazards are within 100m of priority routes. These are located in Auckland City, Manukau City and Rodney District.

31 schools are located within 300m of stored hazardous substances in areas prone to hazards. However, these substances only have low hazard ratios. These schools are located in Waitakere City, Auckland City, North Shore City and Manukau City.

14 emergency services are located within 300m of stored hazardous substances. These are mainly in areas prone to earthquake hazards, and have low hazard ratios. These emergency services are found in Rodney District, North Shore City and Waitakere City.

31% of hazardous substances stored in areas prone to hazards are within 300m of significant natural environments. Some of these have high hazard ratios, and are found in areas mainly prone to earthquake hazards. These are located in Rodney District, Waitakere City, Auckland City and Manukau City.

The top 5% high-risk areas are in North Shore City, Auckland City and Manukau City. Two areas cross TA boundaries, one between Waitakere City and Auckland City, and the other between Manukau City and Papakura District.

Discussion

Most of the high hazard ratio substances are subject to hazards associated with earthquakes, especially amplified ground shaking, rather than flooding. Those substances that are located in hazard zones are not generally located in areas of high population, employment or dwelling densities, therefore minimising risk.

The worst affected elements of emergency response and recovery are likely to be the priority routes as they have only recently been established. Sensitive environments are also exposed to greater risk, likely due to little consideration in the planning process.

Hazardous substances are generally located in close proximity to one another in a number of small areas around the Auckland Region. This is probably the result of zoning, placing reduced restrictions on hazardous substances stored in certain areas. Substances appear to be stored mainly in small quantities, probably due to greater restrictions placed on larger volumes.

This study has found that there is incomplete hazardous substance storage information, and currently any information is spread between sources, and collected in accordance with a number of pieces of legislation (prior to HSNO). Consistency and accurate substance type, location and quantity information is needed. It has also been identified that spatial information on the change in hazard is scarce and could be improved over a number of coastal hazards.

Spatial analysis of risk could be improved with more accurate hazardous substance storage information. Semi-quantitative analyses of risk could be improved with better understanding of release, vulnerability, hazard location and valuing exercises on the impacts of hazardous substance release.

Restriction on how the findings of this report can be presented requires liaison between ARC and territorial authorities to further advance work on sites identified in this report as high risk.

Recommendations

More accurate hazardous substance information needs to be collected including more accurate location data, quantity, and substance information. A more uniform approach to collecting the data would also be advantageous.

It may be possible to create a central repository that would house data in a consistent form for all agencies involved in managing hazardous substances.

The ARC needs to provide information to the territorial authorities to allow further site-specific investigations of those storage facilities identified by this study as high risk.

Greater spatial mapping of variations in risk posed by natural hazards need to be undertaken. Possibilities include fault rupture, coastal hazards (erosion, flooding, tsunami, sea level rise), wildfire and land instability.

Further investigations need to be undertaken into the relationship between hazard and likelihood of rupture of storage containers, vulnerability to different substances, and supporting research into the development of multi-hazard, multi-vulnerability risk analysis methods.

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Introduction

Many activities in the Auckland Region involve the use of hazardous substances, including tank farms, chemical manufacturing companies, swimming pools and associated chlorine gas storage facilities. These all use chemicals that can impact on people and the environment and may include explosive, flammable, oxidising, toxic, corrosive or ecotoxic gasses, liquids or solids. Places that store these sorts of substances are called hazardous facilities.

A range of events may lead to a hazardous substance release including human error, structural failure and natural hazards. The results of a release may include explosions, fires, toxic exposure or spills, leading to consequences such as injury and death, damage to property or infrastructure, or environmental damage.

In most cases, the uncontrolled release of hazardous substances resulting from an accident or natural disaster would probably result in minor and regionally insignificant consequences. However, there are hazardous facilities in the Auckland Region that store quantities of hazardous substances such that they may present a significant risk. These risks are further amplified by the fact that the Auckland Region has a large population with higher densities than elsewhere in New Zealand. There are also significant natural environments and critical emergency response and recovery elements that are vital resources of the region.

Good management begins at the planning stage. This project is aimed at identifying areas storing significant hazardous substances that in the event of a natural disaster could create a significant release of hazardous substances, resulting in the need for a regionally co-ordinated emergency response.

This study looks specifically at the risk posed to the population of the Auckland Region by the release of hazardous substances due to earthquakes and flooding. In addition, this report identifies areas where hazardous substances are stored in areas with high economic vulnerability and in close proximity to emergency response and recovery facilities and sensitive environments.

The database resulting from this exercise will be useful for developing a consistent and effective approach to reducing risk from significant hazardous facilities, and developing satisfactory regional and local response strategies.

The timing of this project is pertinent in light of the present legislative developments relating to managing hazardous substances, in particular the Hazardous Substances and New Organisms Act 1996 (HSNO). Under this new legislation, a number of historical licensing and record-keeping requirements on hazardous substances and facilities may be abandoned. This project provides a 'snapshot' of the current situation that will aid in the safe management of hazardous facilities in the Auckland Region.

The aims of this study are:

- To identify areas where stored hazardous substances present a significant risk in the event of an accidental hazardous substance release caused by an earthquake or flooding;
- To identify gaps in available information;
- To recommend directions for the future use and development of this database.

This will hopefully achieve several outcomes:

- An improved awareness of the risk that hazardous substances pose to the Auckland Region in a natural disaster;
- Identification of the management issues of hazardous substances;
- Improved management of hazardous substances through development of new tools.

Methodology

Summary

This study uses spatial distribution and semi-quantitative methods to assess risk. Specifically this study looks at risk posed to life (population density), economy (employment density, dwelling density), emergency response and recovery elements (priority transport routes, schools, emergency services), and the environment (significant natural environments) due to hazardous substance release resulting from an earthquake or flood event. This study only addressed earthquake and flooding hazards because these are the only two hazards that have been adequately analysed for their spatial variation in risk.

Historically there has been no overarching legislation relating to hazardous substances and therefore data collection is often fragmentary and incomplete. This study collected hazardous substance information from a number of different sources and addressed only those substances stored above a low threshold, allowing assessment of the cumulative effects of several small releases. The dangerous goods databases held by TAs proved to be the most useful and complete record, however, the quality of data varied considerably between TAs. The Occupational Safety and Health (OSH) Explosive Storage Licences also proved a useful source of information.

The aims of this project were achieved by using a number of risk assessment methods. Data collected on hazardous substance was entered in to a GIS database to allow spatial analysis of the location of hazardous substance storage facilities, and the proximity of storage facilities in areas prone to hazards to life, economy, infrastructure and sensitive environments.

1.1 Risk Analysis Approach

This study uses four different approaches to risk assessment.

1. Spatial distribution of substances around the Auckland Region;
2. Spatial analysis of the proximity of hazardous substances to vulnerable elements;
3. Semi-quantitative assessment of risk posed to the Auckland Region population by individual stored substances; and
4. Semi-quantitative assessment of risk posed to the Auckland Region population for substances stored in 500m x 500m blocks.

The initial assessment is an analysis of the distribution of hazardous substance storage in areas prone to liquefaction, amplified ground shaking and flooding in the Auckland Region.

The second assessment involves identifying where hazardous substances are stored in close proximity to vulnerable elements (life, economy, emergency response and recovery elements and environment). This will be undertaken on a regional and territorial authority scale.

The third and fourth methods of assessment involve undertaking a semi-quantitative assessment of the 'risk' posed across the Auckland Region by a hazardous substance release due to an earthquake or flooding. The assessment in 500m x 500m blocks is designed to assess the combined risk of more than one hazardous substance stored in a facility, or a number of storage facilities located in close proximity to one another.

1.1.1 GIS Spatial Analysis

To undertake a spatial analysis of the distribution of substances and vulnerable elements, a GIS approach was taken. Data collected on the location, volume and type of hazardous substance was entered into a GIS database and overlain with flooding and earthquake (liquefaction and amplified ground shaking) maps, and the location of vulnerable elements.

Data was associated with a ground co-ordinate by linking the address field to a GIS address database. Substance locations are therefore only accurate to the land parcel on which they are stored. Data on the substance name, UN class, quantity and container type was also associated with the co-ordinate where available. The natural hazard data was sourced from earlier GIS based projects (see section 1.3).

Distances used when identifying which hazardous substances are located in close proximity to life, economic elements, emergency response and recovery elements and significant natural environments are:

- Life (within surrounding meshblock1)
- Economy (within surrounding meshblock)
- Emergency Response and Recovery Elements
  - Priority transport routes (within 100m)
  - Schools (within 300m)
  - Emergency services (within 300m)
- Significant Environments (within 300m)

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[1] The meshblock is the smallest geographic unit for which statistical data is collected and processed by Statistics New Zealand. A meshblock is a defined geographic area, varying in size from part of a city block to large areas of rural land. Each meshblock abuts against another to form a network covering all of New Zealand including coasts and inlets, and extending out to the two hundred mile economic zone. Meshblocks are added together to 'build up' larger geographic areas such as area units and urban areas. They are also the principal unit used to draw-up and define electoral district and local authority boundaries.

It was beyond the scope of this project to obtain the site-specific data needed to estimate a distance where effects may be felt (e.g. weather conditions, topographical information, storage details, chemical information).

In order to compare the 'hazard' posed by different types of substances, a 'hazard ratio' was calculated that incorporated the quantity of substance stored and the Hazardous Facility Screening Procedure (HFSP) baseline threshold. In this report the significant quantity threshold was initially set at ten times the HFSP baseline thresholds. The equation to calculate the hazard ratio is expressed as:

Hazard Ratio = Quantity of Substance / (HFSP Baseline Threshold x 10) (1)

Therefore, higher hazard ratios suggest a greater potential hazard for that substance. In this study high hazard substances were considered to be those with a hazard ratio greater than 2. Low hazard ratio substances were considered to be those with a hazard ratio less than 2.

1.1.2 Semi-Quantitative Risk Analysis

To undertake semi-quantitative assessment of the risk posed to the population of the Auckland Region by the release of stored hazardous substances due to an earthquake or flooding, a series of calculations were undertaken.

Using census population density information, it was possible to estimate which substances present greater risks to the identified community than others.

The assessment was undertaken using the standard risk identification equation of:

Risk = Hazard x Vulnerability (2)

In this context, the hazard is identified as a factor of the hazard presented by the hazardous substance and the potential for a release to occur:

Hazard = Hazard Ratio x Potential for Release (3)

So the equation is rewritten as:

Risk = (Hazard Ratio x Potential for Release) x Vulnerability (4)

The potential for release is defined as the likelihood of a hazard event and the likelihood of the failure of the storage facility.

Potential for Release = Likelihood of Hazard Occurring x Likelihood of Rupture due to the Hazard Event) (5)

The likelihood of failure of the storage device is difficult to establish due to the lack of data on the type of storage and the rupture potential for the storage device in a hazard event. For this study, it is assumed that there is an equal potential for release from both natural hazards. Flooding is more common than earthquakes, however, an earthquake is more likely to cause an accidental release (based on the assumption that movement of the base of a storage device is likely to be more damaging than immersion in water).

Based on these assumptions the potential for release is equal whenever a substance is located in an area prone to a hazard (i.e. likelihood of flood x likelihood of rupture due to flood = likelihood of liquefaction x likelihood of rupture due to liquefaction = likelihood of amplified ground shaking x likelihood of rupture due to amplified ground shaking). Consequently, a point is attributed for every hazard an area is prone to that a substance is located in. The result is that the potential for a release is a whole number between 0 and 3.

Thus the original equation can be rewritten as:

Risk = (Hazard Ratio x Number of Potential Hazards) x Vulnerability (6)

To establish vulnerability, it was originally intended to assimilate all vulnerable elements to calculate the overall vulnerability. However, to do this a valuing exercise would have to be undertaken to make comparisons between exposing people, emergency response and recovery elements and significant natural environments to the hazard. Upon researching this type of exercise, it was decided that life is clearly valued most highly in risk assessments of this nature. Most assessments only address probabilities of the loss of one or more lives (e.g. Optimix, 2002; Taig, 2002). Other studies have established the dollar value of a life saved (e.g. Miller and Guria, 1991; Guria *et. al.*, 1999) and have found the value of a life saved is in the region of $NZ 2.5 million or greater. Based on this figure, the capital value of all of the built assets in the region are only equal to approximately 2% of the value of life in the region (David Linsey, *pers comm.*). In fact, the hectare of highest capital value in the region is roughly equivalent to a hectare containing 5 lives – a density exceeded for more than 85% of meshblocks in the Auckland Region. Further, It is suggested that errors in the data and process would alter the results by many times the value of capital and environmental assets. For these reasons, it is considered that human life must be the key consideration for assessing the facilities that present the highest risk in the region.

Based on the above findings, vulnerability will be the average population density (see section 1.4.1) in a given meshblock. Thus:

Risk = (Hazard Ratio x Number of Potential Hazards) x Average Population Density (7)

This semi-quantitative method of risk analysis will therefore provide a good indication of the risk to life in the event of hazardous substance release due to earthquakes or flooding. Despite limitations such as an inability to include other vulnerable elements in this calculation, this study still addresses these issues by assessing the spatial distribution of these vulnerable elements and their proximity to hazardous substances stored in areas prone to earthquake and flooding hazards. It is also acknowledged that this risk assessment does not consider wider-reaching and longer term consequences of such a release (e.g. Destruction of the Wiri Oil Terminal would substantially effect Auckland's fuel supply), however it is able to address the immediate, and life-threatening consequences of such an event.

This semi-quantitative measure of risk is only intended to be comparative within this study. An exhaustive quantitative risk assessment would require data that has been unavailable (including storage conditions, flood and earthquake damage assessments of the storage devices) and processing methods that would have been excessively time consuming for a study of this size.

The data needed for this study were the elements of the 'hazard' and 'vulnerability' equations above. This information came from the sources discussed below.

1.2 Hazardous Substance Storage Information

Historically, the legislation enabling the collection of hazardous substances information has been wide spread, and until the drafting of HSNO, there had been no overarching legislation controlling the use, storage, disposal and transport of hazardous substances. As a result there is considerable variation in the quality and accuracy of data that is available on where hazardous substances are stored around the Auckland Region.

Data sources explored include:

- Dangerous Goods Databases
- Toxic Substances Database
- Fire Service Familiarisation Visit Forms
- Occupational Safety and Health (OSH) Explosives Storage Licences
- Defence Forces Information

A screening process was undertaken to remove substances stored in small quantities or those that were not significantly dangerous from further analysis. This was primarily achieved by setting thresholds to be exceeded for a substance to be considered in the analysis.

The thresholds initially established were based on the substance quantities used in the HFSP[2] procedure (see Appendix 1). Those substances that exceeded the HFSP

2 To assist with determining the appropriateness of a site for the storage, use, or disposal of hazardous substances, the territorial authorities have incorporated Hazardous Facilities Screening Procedures (HFSP) into their district plans. HFSP are a method for determining whether a hazardous facility is of sufficiently low risk to be able to operate as a permitted activity (subject to minimum performance standards), or whether the activity poses a significant risk and therefore requires a land use consent. This means that sighting, layout, and management of individual facilities can be of a standard to reduce the risk of accidental release. This method also allows for the consideration of the vulnerability of a hazardous facility to natural hazards because facilities that intend to establish in a natural hazard prone area can be subjected to more stringent controls. However, it appears that this is not currently being implemented to its fullest capacity.

baseline threshold were included for further analysis. A low threshold was set to enable the cumulative effects of several small releases of hazardous substances to be more accurately assessed.

1.2.1 Dangerous Goods Databases

The most useful databases for this study were the dangerous goods databases held by the various territorial authorities. These were established under the now repealed Dangerous Goods Act (1974). Based on this legislation, storage of dangerous goods (as listed in the schedule of the act) within the district administered by local authority should be licensed. All databases included information on the location of the site and the quantity of hazardous substances on the site.

There were variations in other areas of the databases. Some databases listed substances by name, while others identified the substance by the class identified in the Dangerous Goods Act (1974). Data on the storage of the substances varied between databases, from non-existent through to fairly complete records.

The quality of the data also varied between councils. Some records had insufficient data on location, substance type, quantity or units that could not be resolved. The ratio of total records supplied by territorial authorities to the total records that could be used in this analysis is given in Table 1. Further discussion on the problems with this data source is addressed in Section 1.9.

Table 1: Percentage of Dangerous Goods Licence data that was incorporated into the GIS format for analysis.

Territorial Authority	Percentage of data used for analysis
Auckland City Council	100%
Franklin District Council	90%
Manukau City Council	88%
North Shore City Council	100%
Papakura District Council	91%
Rodney District Council	100%
Waitakere City Council	78%

1.2.2 Toxic Substances Database

The repealed Toxic Substances Act (1979) required "every Medical Officer of Health to keep a register of the licences issued by him *(sic)* under the Act" in their district. These licences were issued to allow the sale and packing of those poisons identified by the Toxic Substances Regulations (1983).

The Auckland District Health Board provided this data, although it was of limited value for this study. The data was limited to the address and contact details in the majority of records. Some records also listed chemical names and the 'Schedule of Poison[3]' but quantity of substance was not included.

1.2.3 Fire Service Familiarisation Visit Forms

The fire service undertakes visits around the local community to establish some familiarisation with large firms in the event of a fire. Forms are filled out which detail information such as hazardous substance storage. These forms remain at the local fire station in paper form.

These forms were investigated as a potential source of information but were considered unsuitable. The information on types and quantities of substances is not current as it is based only on the last visit. In addition, significant effort would be needed to convert the paper-based forms to the digital form required for this project.

1.2.4 Occupational Safety and Health (OSH) Explosives Storage Licenses

The Explosives Act (1957) required licensing of the storage of explosives. The HSNO Act (1996) repealed this Act but the information on explosives is still valid as OSH is still operating under the explosives regulations while HSNO is in transition. OSH provided this data for incorporation into the dataset.

The size of the dataset was relatively small in comparison to the dangerous goods licence data, however the substances described present a significant explosive hazard. This hazard can significantly impact the surrounding community as described in this study.

1.2.5 Defence Forces Information

The Dangerous Goods Act (1974), under section 3, does not cover hazardous substances stored on defence land. After speaking with staff from NZ Defence Headquarters, the information on defence storage of hazardous substances, such as explosives and flammable liquids, has been excluded from this study. While there are

3 Schedule of Poison refers to Schedules 1-4 of the Toxic Substances Regulations (1983), which classes substances as either a deadly, dangerous or standard poison, or a harmful substance.

significant security issues surrounding this information, this does not give reason alone to ignore these substances. The reason for their exclusion is that the separation distance between storage facilities and vulnerable communities or environments is greater than the distances used in this study (i.e. there are no schools or priority transport routes on or within 300m of defence facilities due to the security provisions on defence land).

Further, there have been assurances from the NZ Defence that their storage facilities are subject to exceptional safety measures due to the nature of their use in a military context.

1.3 Natural Hazards Information

A comprehensive list of hazards has been compiled (including tsunami, earthquake, fire, flooding and tornados), however only some of these hazards exhibit identifiable spatial variations in risk. For example, the risk of liquefaction is higher in areas that exhibit certain soil characteristics, whereas areas where a tornado strike is more likely are not as easily identified.

Of those hazards exhibiting spatial variation in risk, there can be substantial data requirements to establish the patterns of higher risk throughout the region. As such, the hazards where areas of higher risk have been identified are limited to the three mentioned below:

- Earthquake induced liquefaction (Liq)
- Earthquake induced amplified ground shaking (GS)
- Flooding (Fl)

The identification of these hazard-prone areas is elaborated on in their source documents – the Regional Growth Strategy (Regional Growth Forum, 1997) and the Auckland Engineering Lifelines Stage One Report (Auckland Engineering Lifelines Group, 1999).

The areas prone liquefaction are identified as those soils that are likely to liquefy in an earthquake with a return period of 2000 years. The areas prone to amplified ground shaking are those identified in the AELP as Zones 2 – 4. These areas describe an increasing intensity of ground shaking as the zone number increases (i.e. zone 4 would be subject to the greatest intensity ground shaking). These zones were simplified to one area that describes the area subject to an increase in ground shaking intensity compared with zone 1. Areas identified as prone to flooding hazards are the 1 in 100 year flood levels.

These were then amalgamated to establish areas prone to one hazard (Liq, GS, FI), two hazards (Liq/GS, GS/FI, Liq/ FI) or three hazards (Liq/GS/FI).

1.4 Vulnerable Elements Information

The elements considered in this study as vulnerable are:

Life:

- Population Density

Economy:

- Employment Density
- Dwelling Density

Emergency Response and Recovery Elements:

- Priority transport routes
- Schools
- Emergency services

Environmental:

- Sensitive Environments

1.4.1 Life

Assessment of the impact on the surrounding population and built environment was undertaken using census data. The population and dwelling information from the 2001 census was used to determine densities in the area of the hazardous substance. This information is supplied in meshblocks.

As population differs substantially throughout a day, and a substance release could occur at any time due to a natural hazard, a measure of density needs to be related to the actual number of people present over the course of a day. Two population datasets, daytime population density and night-time population density, were combined to establish this density measure. The daytime population is derived from where people work and study in the region[4]. The census night population provides a figure for

4 Daytime population was obtained from both Census 2001 data and School and Tertiary Institution rolls.

The figure comprised of those who

- worked at home on Census Day
- did not go to work on Census Day
- were over 15 years of age and regarded themselves as unemployed
- were over 15 years of age and regarded themselves as not in the labour force
- were over 15 years of age and worked less than 5 hours per week
- were overseas visitors

the night-time population[5]. Each total is divided by the total number of hectares of the meshblock to establish the population per hectare. This number is a 'gross population density' as it does not remove non-residential land from total area. These figures are then multiplied by 1/3 for daytime population and 2/3 for night-time population (representing the relative time periods spent in each location) in order to calculate the 'average population density'.

1.4.2 Economy

The two economic elements considered in this study are dwelling density (representing the number of vulnerable housing properties) and employment density (the number of jobs that may be affected).

Dwelling density is the total number of dwellings recorded by the 2001 census, divided by the number of hectares of the meshblock. Again, this value is a gross figure.

Employment density is derived from the business directory data from Statistics New Zealand and is again based on meshblocks. The number of full time employees or 'full time equivalents' is divided by the area of each meshblock and provided as a gross figure. This provides information on the effect of a release on business, given that a release in an area of high employment density is likely to have a larger impact on the economy than a release in an area with lower employment density.

1.4.3 Emergency Response and Recovery Elements

Priority transport routes are those parts of the roading network that will have priority in being re-established in the event of a natural disaster. The routes have been identified in the Priority Emergency Routes Report (Auckland Engineering Lifelines Group, 2001). The routes used in the assessment are those identified in the report as motorways and emergency routes (i.e. alternative routes are not considered).

Schools are considered emergency response and recovery facilities in this study as they can provide emergency meeting places and/or housing in the event of an emergency. School locations are derived from a 1997 Ministry of Education list of all primary, intermediate and secondary schools in the Auckland Region. This list identifies 501 schools that were used in the analysis.

- were under the age of 5 years

Added to this was the total number of persons who travelled to work on Census Day

From the education rolls were added

- student numbers at each school
- student numbers at each tertiary institution

5 The night time population used only two elements from the Census Data

- the Usually Resident Population
- overseas visitors

The location of emergency services facilities identified for this project were gathered from CDEMG Co-ordinating and Advisory Committee representatives for the Police, Fire Service, St Johns, and the three District Health Boards (DHB). Police stations identified are those that contain a unit response. The locations of fire and ambulance stations are also identified. The nine public hospitals licensed by the DHB in the region have also been located and imported into this project.

1.4.4 Environment

The significant natural environments described in this study are those defined in the ARC Natural Heritage Significant Natural Areas database and Department of Conservation Sites of Special Wildlife Interest database. These areas are described as significant areas of indigenous vegetation and wildlife habitat.

Results

Summary

77% of hazardous substances are located in areas prone to hazards. Those associated with high population density and high hazard ratios are located in Auckland City. Those that have a high hazard ratio and high employment and swelling densities are in Auckland City, Manukau City and Waitakere City. These substances are stored mainly in areas prone to earthquake-induced hazards.

45% of hazardous substances stored in areas prone to hazards are within 100m of priority transport routes. These are located in Auckland City, Manukau City and Rodney District.

31 schools are located within 300m of stored hazardous substances in areas prone to hazards. However, these substances only have low hazard ratios. These schools are located in Waitakere City, Auckland City, North Shore City and Manukau City.

14 emergency services are located within 300m of stored hazardous substances. These are mainly in areas prone to earthquake hazards, and have low hazard ratios. These emergency services are found in Rodney District, North Shore City and Waitakere City.

31% of hazardous substances stored in areas prone to hazards are within 300m of significant natural environments. Some of these have high hazard ratios, and are found in areas mainly prone to earthquake hazards. These are located in Rodney District, Waitakere City, Auckland City and Manukau City.

The top 5% high-risk areas are in North Shore City, Auckland City and Manukau City. Two areas cross TA boundaries, one between Waitakere City and Auckland City, and the other between Manukau City and Papakura District.

The results reported in this document will be limited to a statistical analysis of the hazardous substances located in areas prone to hazards, and the makeup of the surrounding community and environment. Whilst a more accurate spatial description is possible, constraints due to confidentiality issues limit the results that may be presented in this report. More specific details are available in Appendices 3 – 9 and on request from the ARC for each Territorial Authority.

1.5 Distribution of Hazardous Substances

For this study, 1274 hazardous substances were identified as exceeding the thresholds for GIS analysis (See section 1.2). The distribution of hazard ratios across the region is presented in Table 2.

Table 2: Distribution of hazard ratio for the entire Auckland Region.

Ratio	Frequency	Percentage
0.1-	846	66.41
0.5-	222	17.43
1-	103	8.08
2-	38	2.98
3-	17	1.33
5-	11	0.86
10-	15	1.18
25-	4	0.31
50-	5	0.39
100-	13	1.02

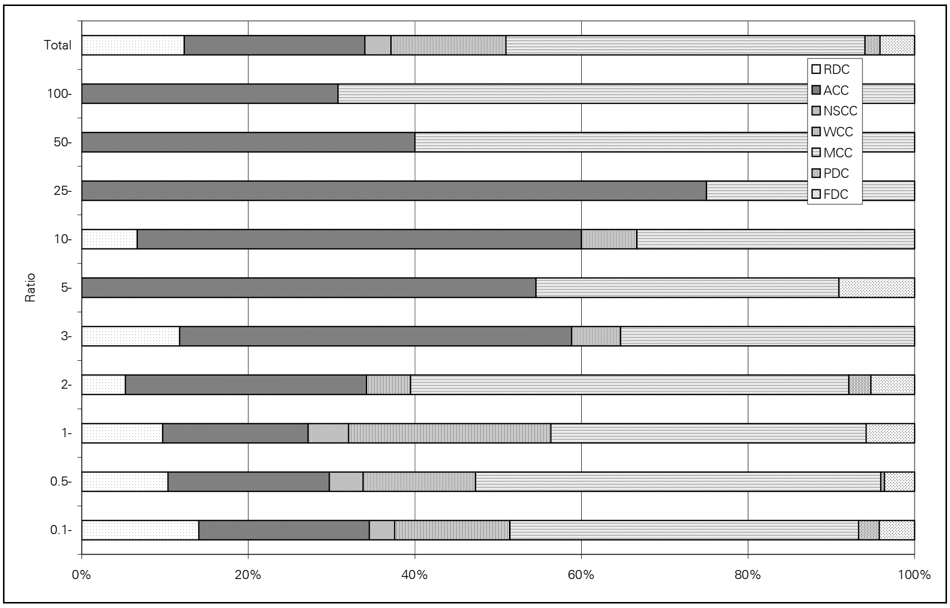
The breakdown of hazardous substances by territorial authorities is presented in Table 3. The majority of hazardous substances are stored in Manukau City, followed by a large number in Auckland City, then Waitakere City and Rodney District. Relatively small numbers of hazardous substances are found in Franklin and Papakura Districts and North Shore City.

Table 3: Frequency of hazardous substances by territorial authority and hazard ratio.

Ratio	ACC	FDC	MCC	NSCC	PDC	RDC	WCC
0.1-	173	36	354	26	21	119	117
0.5-	43	8	108	9	1	23	30
1-	18	6	39	5	0	10	25
2-	11	2	20	0	1	2	2
3-	8	0	6	0	0	2	1
5-	6	1	4	0	0	0	0
10-	8	0	5	0	0	1	1
25-	3	0	1	0	0	0	0
50-	2	0	3	0	0	0	0
100-	4	0	9	0	0	0	0
Total	276	53	549	40	23	157	176

Figure 1 shows the distribution of hazardous substances between territorial authorities in hazard ratio bands. This shows that Manukau City has the highest total proportion of hazardous substances stored in the region. However, the higher hazard ratio substances are distributed approximately evenly in both Auckland and Manukau Cities, while Manukau City has the greatest proportion of substances in the lower hazard ratio bands. Hazardous substances stored in other territorial authorities have only low hazard ratios, however there are a number of these located in North Shore City and Papakura District.

Figure 1: Percentage contribution from each territorial authority to the hazard ratio total of the Auckland Region.



Of these hazardous substances approximately 77% are located in an area prone to at least one of the hazards identified for this study. The distribution of the hazard ratios of these substances is presented in

Figure 2, which shows that those substances located in areas prone to flooding or earthquake hazards have predominantly low hazard ratios. In this study 3% of hazardous substances are located in areas prone to flood hazard, 24% were located in areas prone to liquefaction, and 76% were located in areas prone to amplified ground shaking. Table 4 and Figure 3 show this summary.

Figure 2: Distribution of hazard ratios for hazardous substances located in areas prone to hazards

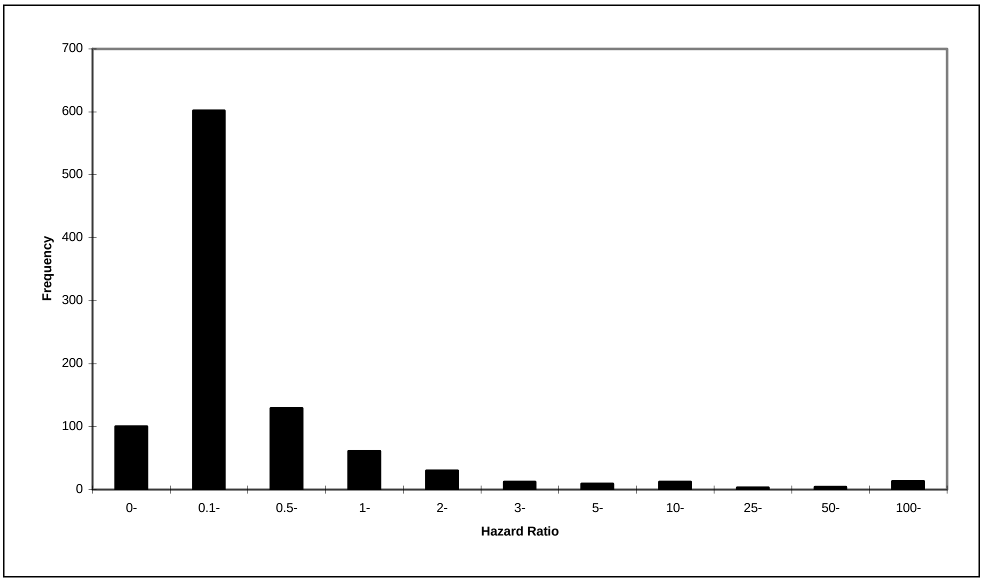


Table 4: Distribution of hazardous substances in the Auckland Region by hazard ratio: areas prone to Flooding (Fl), Liquefaction (Liq), Amplified Ground Shaking(GS).

Ratio	Fl	Liq	GS	Fl/Liq	Liq/GS	Fl/GS	Fl/Liq/GS	None
0.1-	5	0	415	0	192	8	13	213
0.5-	0	0	128	0	42	1	3	48
1-	0	0	59	0	11	5	2	26
2-	0	0	17	0	17	0	0	4
3-	0	0	8	0	6	0	0	3
5-	0	0	5	0	5	0	0	1
10-	0	0	7	0	5	0	0	3
25-	0	0	1	0	3	0	0	0
50-	0	0	3	0	1	0	0	1
100-	0	0	9	0	4	0	0	0
Total	5	0	652	0	286	14	18	299

Figure 3: Percentage of hazardous substances at risk from hazards in the Auckland Region. Further broken down into hazard ratio intervals.

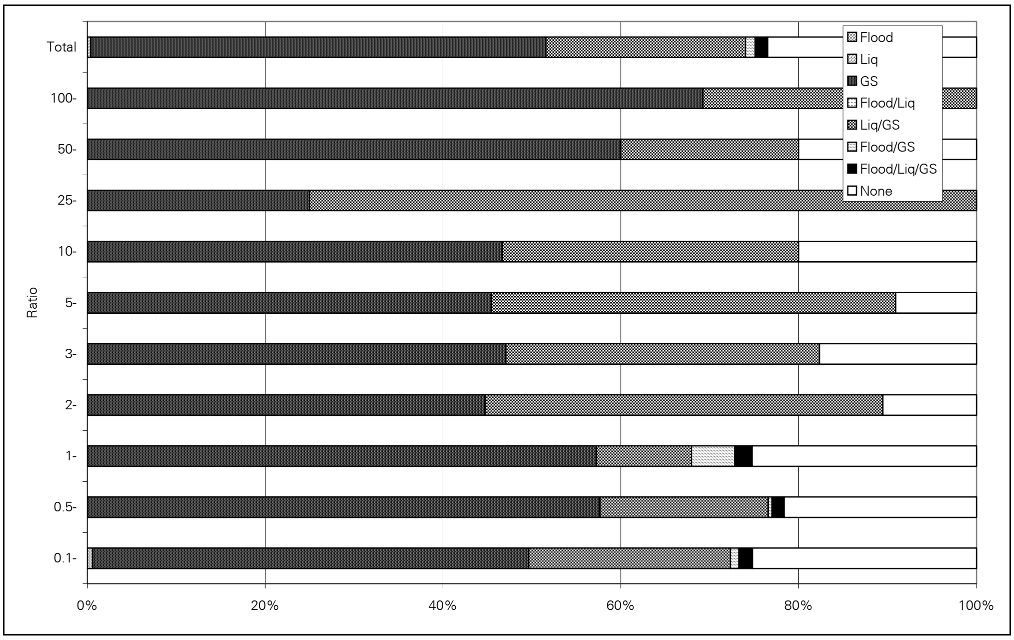


Figure 3 shows that the majority of substances in the Auckland Region are located in areas prone to amplified ground shaking (GS) alone. Greater than 20% of hazardous substances are stored outside all areas prone to the hazards identified in this study (None) and also in areas prone to both liquefaction and amplified ground shaking hazards (Liq/GS). Comparatively, the number of hazardous substances stored in areas prone to flooding (Fl), flooding and amplified ground shaking (Fl/GS) and flooding, liquefaction and amplified ground shaking (Fl/Liq/GS) are very low. There are no substances stored in areas prone solely to liquefaction (Liq) or flooding and liquefaction (Fl/Liq).

Most of the substances with very high hazard ratios are located in areas prone to at least one hazard. These substances are more frequently found in areas prone to GS or Liq/GS. Most other hazard prone areas only contain substances with lower hazard ratios.

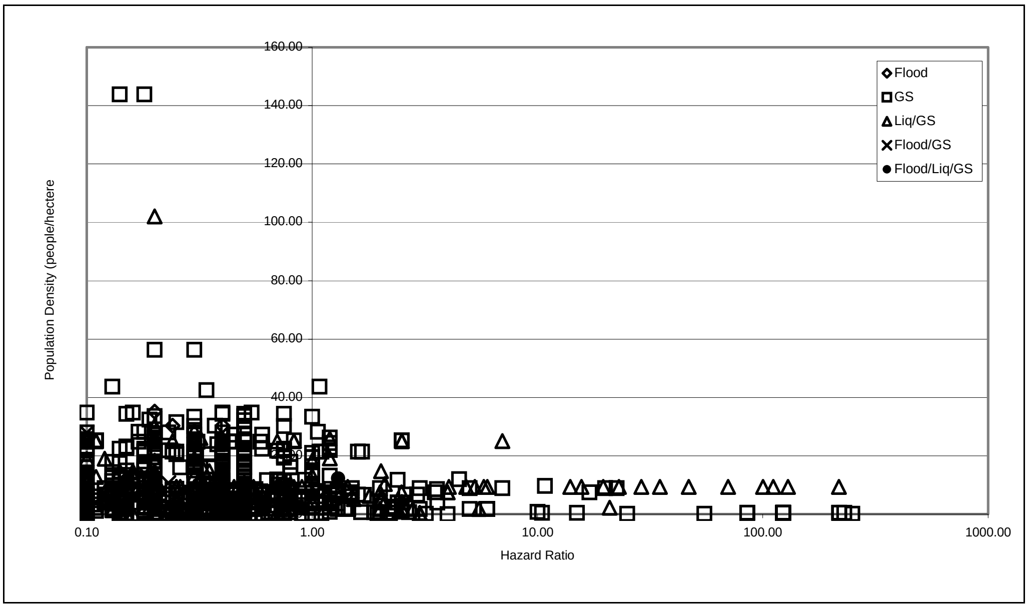
1.6 Proximity to Vulnerable Elements

This analysis assesses the proximity of vulnerable elements to stored hazardous substances, and identifies predominantly those hazardous substances with high hazard ratios that are within the distances set out in section 1.1.1.

1.6.1 Life - Average Population Density

The majority of hazardous substances that are stored in areas prone to hazards are areas with low average population density. However, a few substances are found in areas of quite high population density (see Figure 4).

Figure 4: Hazard ratio versus average population density for all hazardous substances in areas prone to hazards in the Auckland Region. (Note Logarithmic scale on x axis, y axis cuts at x = 1)



In Figure 4 average population densities have been plotted against hazard ratios for those substances in areas prone to hazards, providing an approximate indication of the hazard presented to the population. In areas where a high hazard ratio substance is stored in an area with a high average population density, the risk of death or injury resulting from an uncontrolled release will be greater, whilst the lowest risk is associated with low values of hazard ratio and population density.

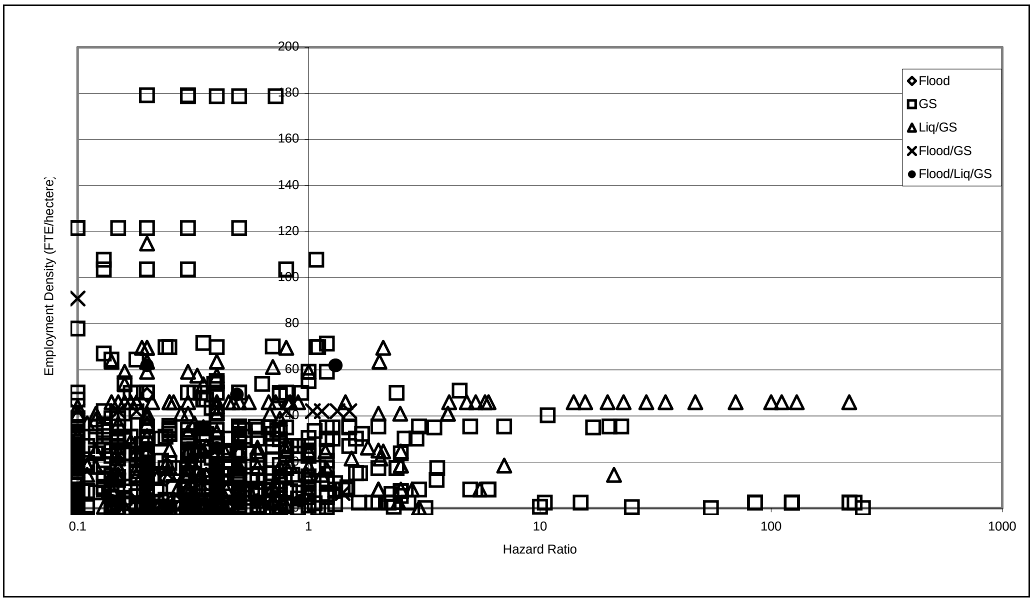
Most substances have low hazard ratios and are stored in areas with low population densities. These are found in areas prone to a range of hazards. There are a significant number of stored substances that have either high hazard ratios or are stored in areas with high population densities. These are mainly made up of substances found in areas prone to GS or both GS and Liq hazards.

There are few substances that have a high hazard ratio and are found in areas with high population densities. Those that do are predominantly in areas prone to GS or Liq/GS hazards. These substances (in this case considered to be where hazard ratio >2 and population density > 20 per hectare) are only stored in Auckland City, in the waterfront area and Otahuhu.

1.6.2 Economy - Employment Density

Hazardous substances are stored in areas of varying employment density. As with population density, substances are mostly stored in areas of lower employment density, however there is a greater spread exhibited (see Figure 5).

Figure 5: Hazard ratio versus employment density for all hazardous substances in areas prone to hazards in the Auckland Region. (Note Logarithmic scale on x axis, y axis cuts at x =1)



Those substances that have high hazard ratios are stored in areas of high employment density are found in areas prone to Liq/GS and GS hazards. Substances with either high hazard ratios or high employment densities are also stored in areas prone to Fl/GS, Fl/Liq/GS or Fl hazards.

A total of 38 substances have a hazard ratio greater than 2 and are located in areas where the employment density is greater than 20 people per hectare. These substances are located in Auckland City (waterfront area, Rosebank road, Mt Wellington, Penrose, Onehunga), Manukau City (East Tamaki, Otahuhu, Howick), and Waitakere City (New Lynn).

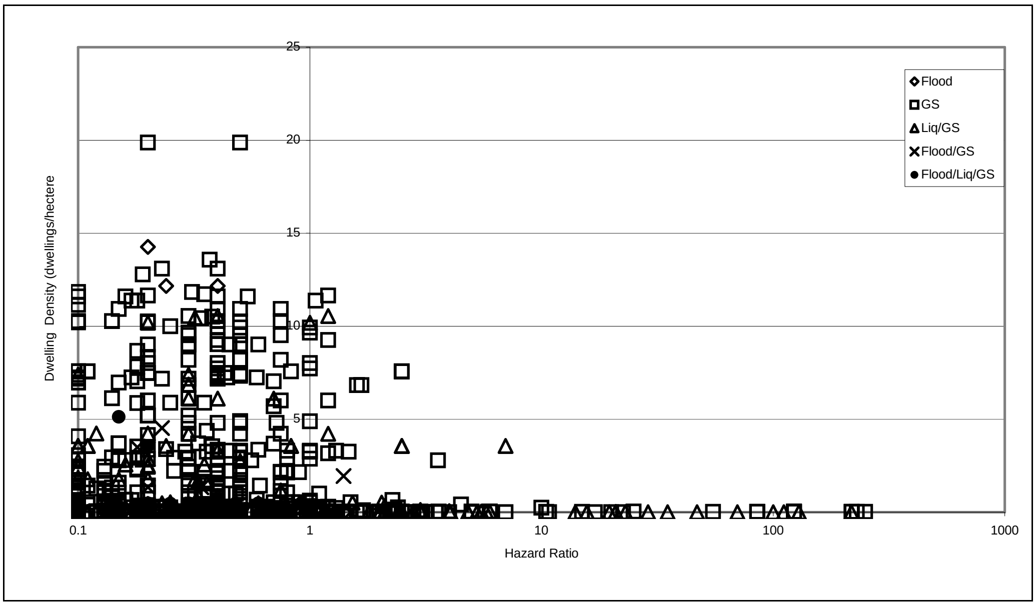
1.6.3 Economy - Dwelling Density

The dwelling density varies in areas where hazardous substances are stored in areas prone to hazards, however low densities are the most common (see Figure 6).

The greatest risk is predominantly associated with hazardous substances in areas prone to GS and Liq/GS hazards. Some substances located in areas prone to Fl/Liq/GS, Fl/GS and Fl hazards are also associated with high dwelling densities but have low hazard ratios.

Those substances that have a dwelling density of greater than 2 and a hazard ratio greater than 2 are the same as those identified as having high hazard ratios and high average population densities are located in Auckland City (waterfront area, Rosebank road, Mt Wellington, Penrose, Onehunga), Manukau City (East Tamaki, Otahuhu, Howick), Waitakere City (New Lynn) and Auckland City (Glen Innes).

Figure 6: Hazard ratio versus dwelling density for all hazardous substances in areas prone to hazards in the Auckland Region. (Note Logarithmic scale on x axis, y axis cuts at x =)



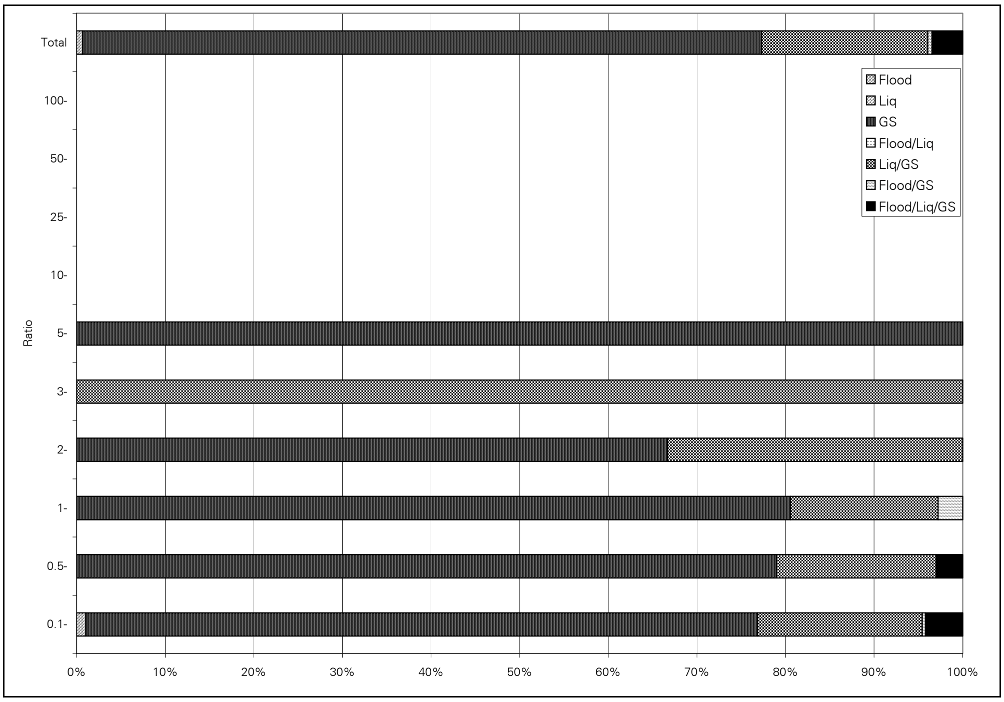
1.6.4 Emergency Response and Recovery – Priority Transport Routes

Of the 965 hazardous substances in areas prone to hazards in the Auckland Region, 432 are also located within 100m of a priority transport route (see Table 5). These are mostly located in areas prone to GS or Liq/GS hazards. This is also the case with those hazardous substances with higher hazard ratios.

Table 5: Number of hazardous substances recorded within an area prone to hazards and within 100m of a priority transport route.

Ratio	Fl	Liq	GS	Fl/Liq	Liq/GS	Fl/GS	Fl/Liq/GS
0.1-	3	0	216	0	53	1	12
0.5-	0	0	79	0	18	0	3
1-	0	0	29	0	6	1	0
2-	0	0	6	0	3	0	0
3-	0	0	0	0	1	0	0
5-	0	0	1	0	0	0	0
10-	0	0	0	0	0	0	0
25-	0	0	0	0	0	0	0
50-	0	0	0	0	0	0	0
100-	0	0	0	0	0	0	0
Total	3	0	331	0	81	2	15

Figure 7: Graph of hazardous substances located in an area prone to hazards and within 100m of a priority transport route. Figures expressed as percentages of the total in each hazard ratio band.



Hazardous substances that are stored within 100m of a priority transport route and have a hazard ratio of greater than 2 are located in: Auckland City (Onehunga, Otahuhu, and Rosebank Road), Manukau City (Otahuhu, Manukau and East Tamaki), and Rodney (Woodhill) (see Figure 7).

1.6.5 Emergency Response and Recovery - Schools

Across the Auckland Region 83 hazardous substances are located in areas prone to earthquakes and flooding and are within 300m of a school (see Table 6 and Figure 8). However, these substances have hazard ratios below 3 suggesting fairly low risk.

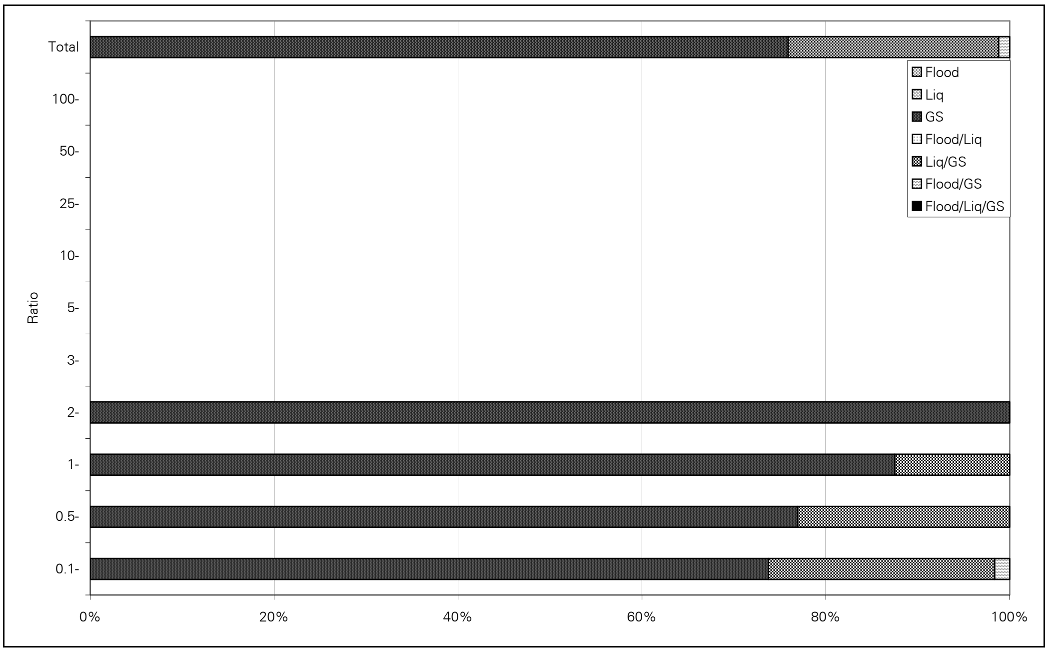
This affects 31 schools across the Auckland Region and suggests that multiple hazardous substances may surround many of the schools identified. However, this only represents a small percentage of the schools across the region (6%).

The substances that have a hazard ratio of 1 or higher and that are within 300m of a school are located in Waitakere City (Henderson), Auckland City (Tamaki), North Shore City (Milford) and Manukau City (Manurewa, Otara, Papatoetoe).

Table 6: Number of hazardous substances recorded within an area prone to hazards and within 300m of a school.

Ratio	Fl	Liq	GS	Fl/Liq	Liq/GS	Fl/GS	Fl/Liq/GS
0.1-	0	0	45	0	15	1	0
0.5-	0	0	10	0	3	0	0
1-	0	0	7	0	1	0	0
2-	0	0	2	0	0	0	0
3-	0	0	0	0	0	0	0
5-	0	0	0	0	0	0	0
10-	0	0	0	0	0	0	0
25-	0	0	0	0	0	0	0
50-	0	0	0	0	0	0	0
100-	0	0	0	0	0	0	0
Total	0	0	64	0	19	1	0

Figure 8: Graph of hazardous substances located in an area prone to hazards and within 300m of a school. Figures expressed as percentages of the total in each hazard ratio band.



1.6.6 Emergency Response and Recovery - Emergency Services

14 of the 77 emergency services facilities identified in this study are located within 300m of a hazardous substance stored in areas prone to earthquake or flooding hazards. 8 of these are police facilities, 3 are ambulance stations, 2 are hospitals and 1 fire station.

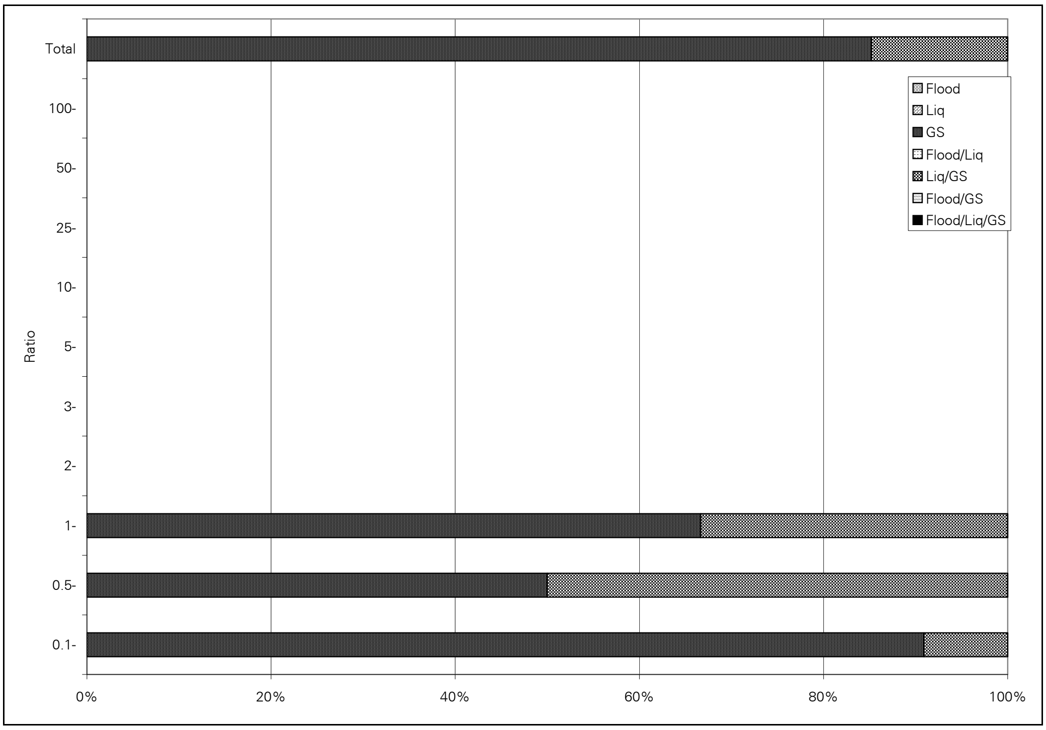
Only 27 hazardous substances are located within 300m of an emergency service facility and are also in areas prone to earthquake or flooding hazards. All of these substances have low hazard ratios, which decrease the potential threat to the Emergency Service facilities. All substances are located in areas prone to GS or GS/Liq hazards (see Table 7, Figure 9).

Substances that have a hazard ratio of 1 or more and are also within 300m of an emergency services facility are found in Rodney (Orewa), North Shore City (Milford) and Waitakere City (Henderson).

Table 7: Number of hazardous substances recorded within an area prone to hazards and within 300m of an emergency service facility.

Ratio	Fl	Liq	GS	Fl/Liq	Liq/GS	Fl/GS	Fl/Liq/GS
0.1-	0	0	20	0	2	0	0
0.5-	0	0	1	0	1	0	0
1-	0	0	2	0	1	0	0
2-	0	0	0	0	0	0	0
3-	0	0	0	0	0	0	0
5-	0	0	0	0	0	0	0
10-	0	0	0	0	0	0	0
25-	0	0	0	0	0	0	0
50-	0	0	0	0	0	0	0
100-	0	0	0	0	0	0	0
Total	0	0	23	0	4	0	0

Figure 9: Graph of hazardous substances located in an area prone to hazards and within 300m of an emergency services facility. Figures expressed as percentages of the total in each hazard ratio band.



1.6.7 Environment - Significant Natural Environments

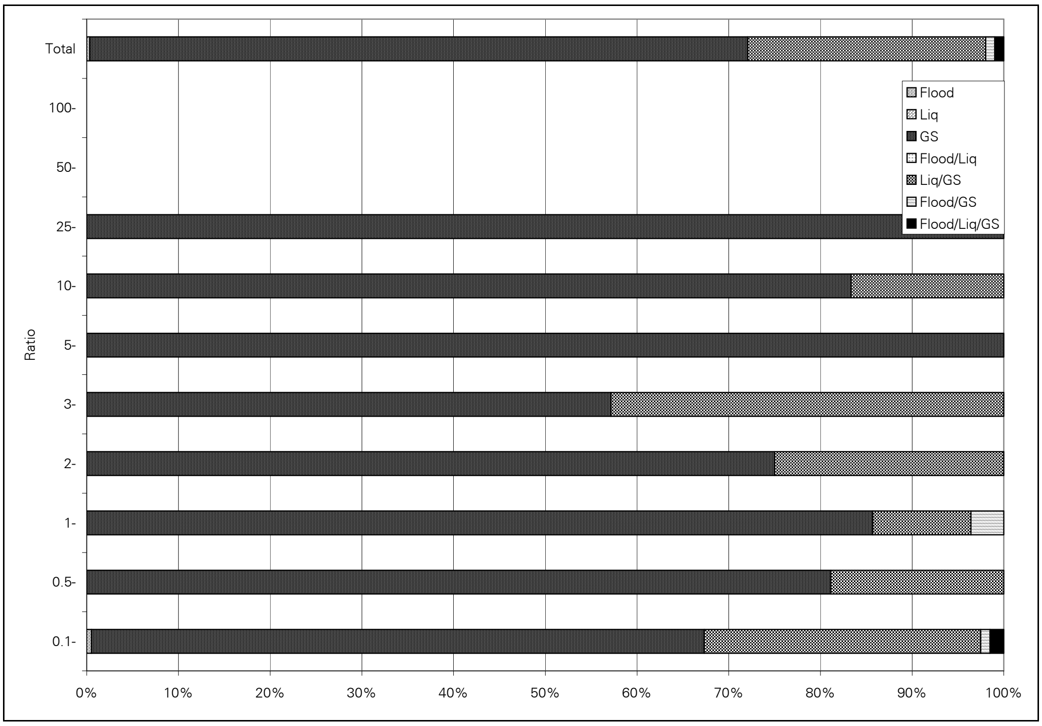
Table 8 and Figure 10 show the relative risk of a hazardous substance release near a naturally significant area. These hazardous substances are mostly found in areas prone to amplified ground shaking across all hazard ratios (which are as high as 25). Many hazardous substances are also located in areas prone to Liq/GS hazards, which further exacerbates the threat posed by an earthquake to areas of natural significance. There are only minor numbers of hazardous substances located close to significant natural environments and located in areas prone to flooding hazards.

The substances that are located within 300m of a significant natural environment and have hazard ratios of greater than or equal to 3 are found in Rodney (Point Wells), Waitakere City (New Lynn), Auckland City (Mt Wellington) and Manukau City (Otara, East Tamaki, Mangere).

Table 8: Number of hazardous substances recorded within an area prone to hazards and within 300m of an area of natural significance.

Ratio	Fl	Liq	GS	Fl/Liq	Liq/GS	Fl/GS	Fl/Liq/GS
0.1-	1	0	133	0	60	2	3
0.5-	0	0	43	0	10	0	0
1-	0	0	24	0	3	1	0
2-	0	0	6	0	2	0	0
3-	0	0	4	0	3	0	0
5-	0	0	2	0	0	0	0
10-	0	0	5	0	1	0	0
25-	0	0	1	0	0	0	0
50-	0	0	0	0	0	0	0
100-	0	0	0	0	0	0	0
Total	1	0	218	0	79	3	3

Figure 10: Graph of hazardous substances located in an area prone to hazards and within 300m of a naturally significant area. Figures expressed as percentages of the total in each hazard ratio band.



1.7 Semi-Quantitative Assessment of Risk Posed by Hazardous Substances & Facilities

The previous section has highlighted the locations where hazard ratios are high and in close proximity to important or vulnerable elements. However, as mentioned in section 3.3.3, in order to determine the risk posed by the storage of hazardous substances in areas prone to earthquake and flooding hazards, both the hazard posed by a substance and the vulnerability of the community must be considered. Consequently, we wish to identify those areas where hazardous substances pose the greatest risk to surrounding communities. Secondly, we wish to identify the general areas that are exposed to the greatest risk. This will consider the combined impact of a number of hazardous substances stored in close proximity to one another. In order to do this the region was divided into 500m x 500m square areas and the risk values of all substances in each area were summed, providing a ‘cumulative risk value’.

1.7.1 Individual Substances

The 975 individual substances located in areas prone to earthquake or flooding hazards have a mean risk value of 23.6, with values ranging from 0 up to 4070. The mean risk value is significantly skewed by the few outlying high-risk values (see Figure 13). The risk value is made up of a mean hazard value of 4.41 and a mean vulnerability value of 9.44.

Figure 11: Histogram showing the distribution of hazard values for substances in an area prone to hazards. Note the uneven distribution of hazard values on the x-axis.

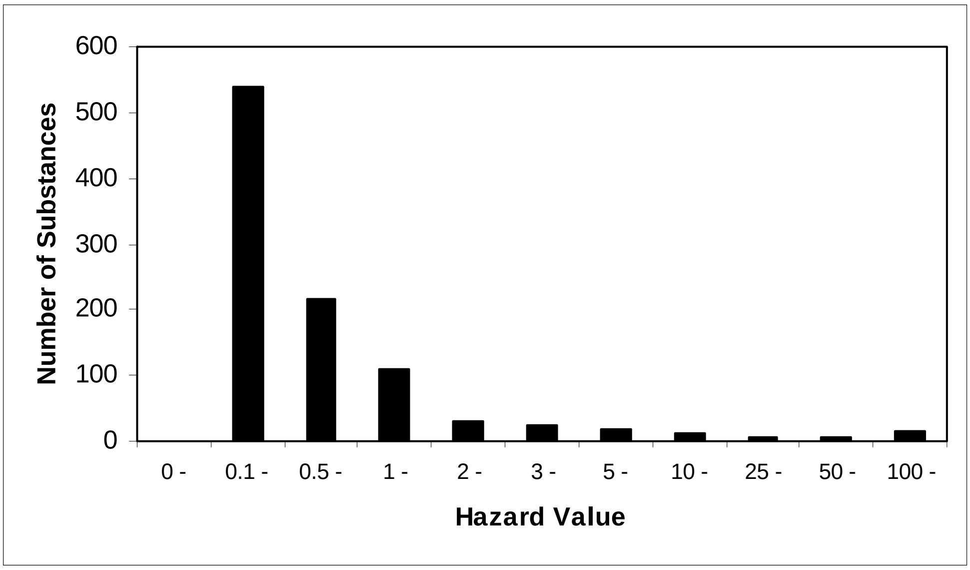


Figure 12: Histogram showing the distribution of vulnerability values around substances stored in an area prone to hazards. Note the uneven distribution of meshblock population density values on the x-axis.

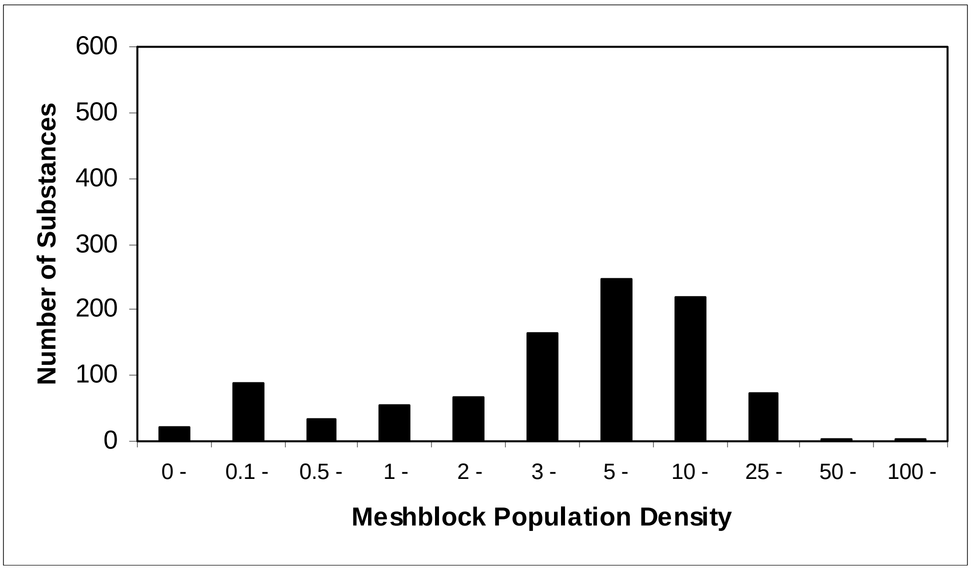
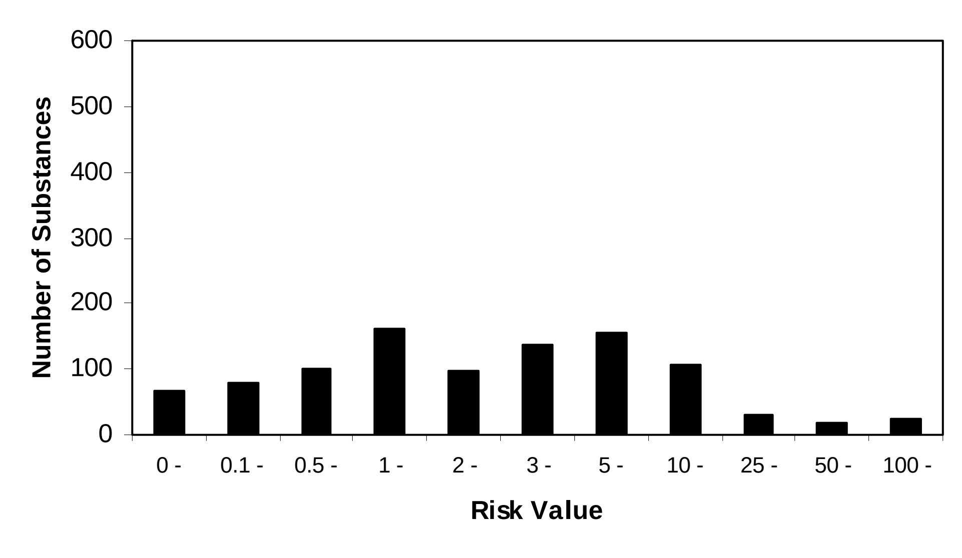


Figure 13: Histogram showing the distribution of risk values around substances stored in an area prone to hazards. Note the uneven distribution of risk values on the x-axis.



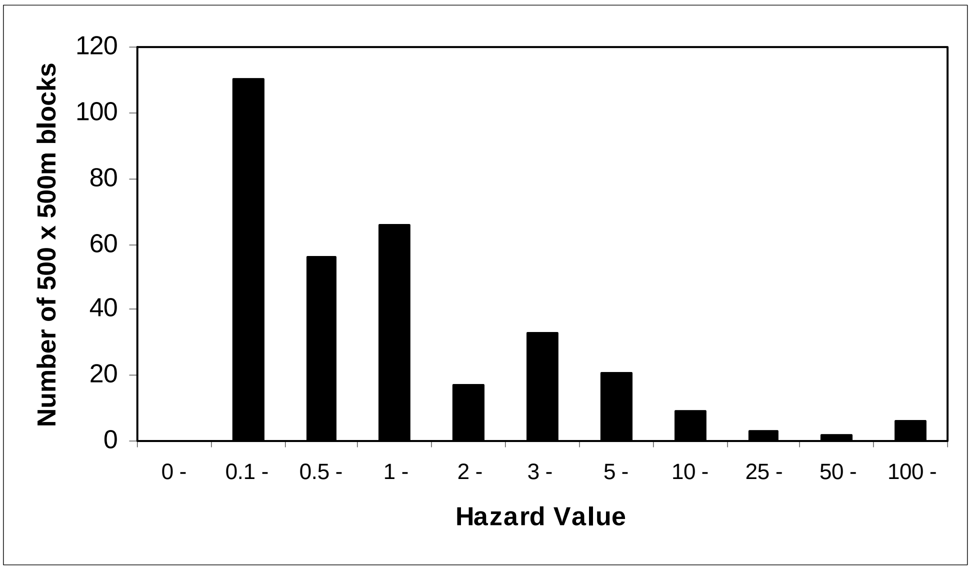
Hazard values (see Equation 3) show a similar distribution (see Figure 11) to the distribution of the hazard ratios as shown in Figure 2. Vulnerability (average population density, see Section 3.3.3) displays a more normal distribution, with a peak further along the x-axis at between 5 to 10 people/hectare, which has the effect of more evenly distributing the risk values (see Figure 12).

Those substances that have a risk value of greater than 42 (the top 5%) are located in Waitakere City (New Lynn), Auckland City (waterfront, Mt Wellington, Penrose, Otahuhu), Manukau City (Manukau, Mangere, East Tamaki, Howick, Manurewa Otara), and North Shore City (Takapuna, Milford).

1.7.2 Cumulative Risk

In order to assess the cumulative risk in areas around the Auckland Region, each of the risk, vulnerability and hazard values were summed in 500m x 500m squares. This reduces the number of records by around a third. The distribution of cumulative hazard and vulnerability values are similar to that of individual substances (see Figure 14 and Figure 15). Hazard values are typically low but the distribution of vulnerability values peak at a higher value. This results in a more even distribution of risk values (see Figure 16).

Figure 14: Histogram showing the distribution of hazard values for each 500m x 500m square that contains a substance in an area prone to hazards. Note the uneven distribution of hazard values on the x-axis.



The areas where the cumulative risk exceeds 90 (the top 5%) are North Shore City (Takapuna), Auckland City (waterfront area, Otahuhu, Mt Wellington) and Manukau City (East Tamaki, Mangere/International Airport, Manukau). Two other areas cross TA boundaries, one on the boundary of WCC and ACC (New Lynn), and one on the boundary of MCC and PDC (Manurewa).

The mean hazard value shifts up slightly to 13.33, reflecting the grouping of substances together in these 500m x 500m squares. The mean vulnerability value also increases to 28.51. The mean cumulative risk then increases significantly to 71.24.

Figure 15: Histogram showing the distribution of vulnerability values for each 500m x 500m square that contains a substance in an area prone to hazards. Note the uneven distribution of meshblock population density values on the x-axis.

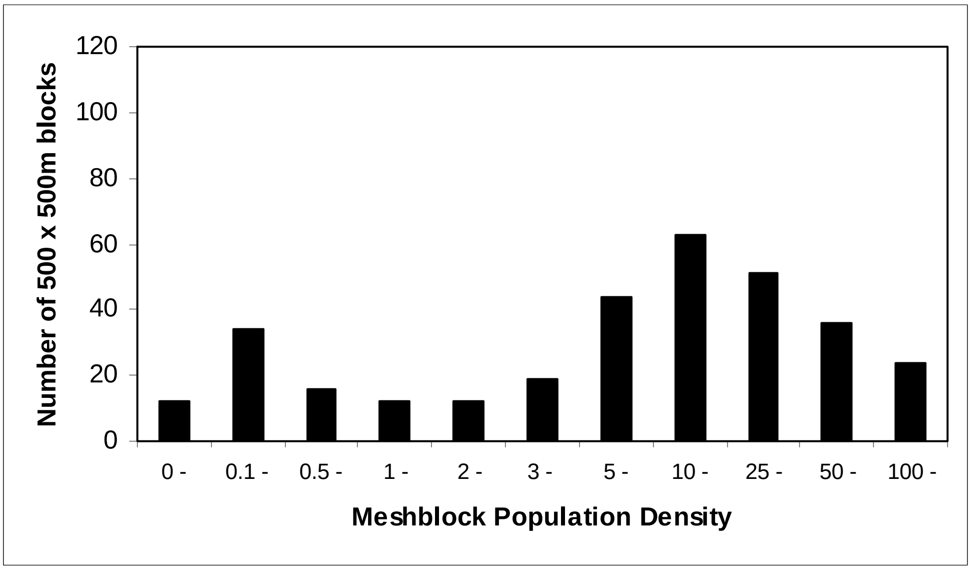
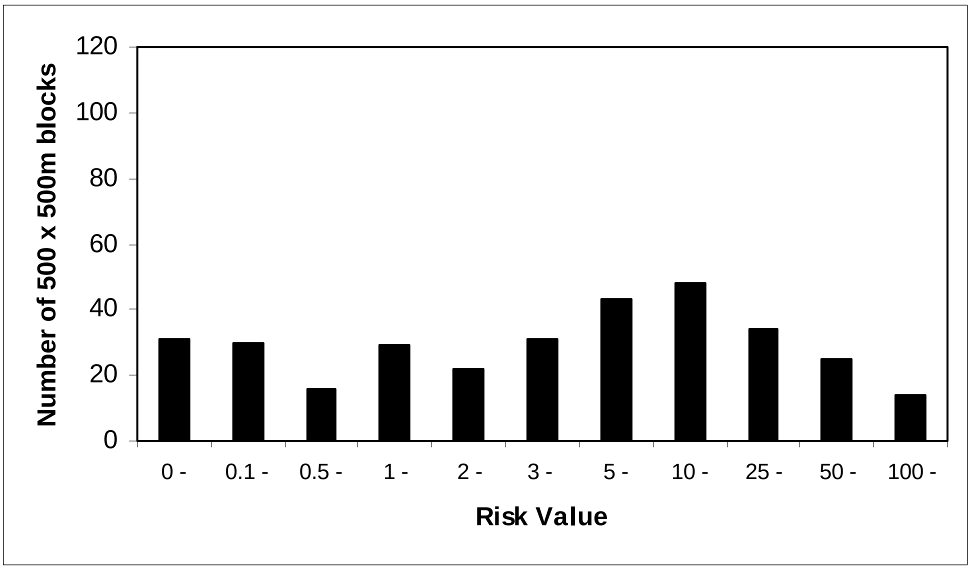


Figure 16: Histogram showing the distribution of risk values for each 500m x 500m square that contains a substance in an area prone to hazards. Note the uneven distribution of risk values on the x-axis.



Discussion

Summary

Most of the high hazard ratio substances are subject to hazards associated with earthquakes, especially amplified ground shaking, rather than flooding. Those substances that are located in an area prone to hazards are not generally located in areas of high population, employment or dwelling densities, therefore minimising risk.

The worst affected elements of emergency response and recovery are likely to be the priority transport routes as they have only recently been established. Sensitive environments are also exposed to greater risk, likely due to little consideration in the planning process.

Hazardous substances are generally located in close proximity to one another in a number of small areas around the Auckland Region. This is probably the result of zoning, placing reduced restrictions on hazardous substances stored in certain areas. Substances appear to be stored mainly in small quantities, probably due to greater restrictions placed on larger volumes.

This study has found that there is incomplete hazardous substance storage information, and currently any information is spread between sources, and collected in accordance with a number of pieces of legislation (prior to HSNO). Consistency and accurate substance type, location and quantity information is needed. It has also been identified that spatial information on the change is hazard is scarce and could be improved over a number of coastal hazards.

Spatial analysis of risk could be improved with more accurate hazardous substance storage information. Semi-quantitative analyses of risk could be improved with better understanding of release, vulnerability, hazard location and valuing exercises on the impacts of hazardous substance release.

Restriction on how the findings of this report can be presented requires liaison between ARC and territorial authorities to further advance work on sites identified in this report as high risk.

1.8 High-Risk Hazardous Substance Storage Locations

Risk assessment results are only comparative within this study, as the lack of complete information necessitated the approximation of hazard and vulnerability values. The semi-quantitative measures of risk do not encompass all of the vulnerable elements assessed in this study, as the valuing required for such an assessment has not been undertaken.

The confidential Appendices 3–9 supplement the conclusions presented in this section and contain more detailed information for each Territorial Authority in the Auckland Region.

1.8.1 Distribution of Hazardous Substances

Manukau City has disproportionately more hazardous substances stored in the region by number, followed by Auckland City, Waitakere City and then Rodney District. Relatively few hazardous substances are found in the Franklin and Papakura Districts and North Shore City.

Approximately 84% of the hazardous substances identified in this study were stored in quantities lower than the threshold determined as 'regionally significant'. This suggests that of the substances considered significant for planning purposes (i.e. those that exceed HFSP thresholds) only the top 16% of these are significant on a regional scale. The value considered as regionally significant is somewhat arbitrary as there may be a number of factors that could cause a release to be regionally significant other than just quantity and type of substance, including wind direction, proximity of water and whether the substance is a gas, liquid or solid.

As expected, as the hazard ratio increased, the number of stored hazardous substances in that hazard ratio range decreased. This suggests that it is preferable to store smaller quantities of hazardous substances rather than larger quantities, probably due to the increased controls placed on substances stored in larger quantities.

If regional scale impacts were solely dependent on the hazard ratios established for this study, those territorial authorities exposed to the greatest risk would be Auckland and Manukau City as they contain greatest number of substances with high hazard ratios. Rodney and Franklin Districts and Waitakere City would be exposed to moderate risk and North Shore and Papakura, with mostly low hazard ratio substances, would be exposed to the lowest risk.

77% of hazardous stubstances in the Auckland Region are stored in areas prone to hazards. These substances are mainly stored in areas prone amplified ground shaking and/or liquefaction. In addition, high hazard ratio substances are predominantly found in areas prone to amplified ground shaking and/or liquefaction. Clearly earthquakes have the greater potential to cause release of these stored substances than flooding. It needs to be highlighted that the return period of the hazard described in these areass is much greater than that in areas prone to flooding (i.e. a 1 in 2000 year return period versus a 1 in 100 year return period). However, it was determined to be a sensible comparison as a 1 in 2000 year earthquake is probably just as likely to result in complete failure of hazardous substance storage structuresas would similar magnitude flood (i.e. a 1 in 2000 year return period) within a 1 in 100 year floodplain.

Results suggest that flooding will only affect hazardous substances that have a low hazard ratio (see Figure 3), and is unlikely to cause a regionally significant hazardous substance release based on hazard ratio magnitudes. In the event of an earthquake, more hazardous substances will be subject to amplified ground shaking than liquefaction, and could cause a regionally significant release through either liquefaction or amplified ground shaking.

1.8.2 Proximity to Vulnerable Elements

The hazard increases where there are substances nearby with high hazard ratios, a large number of substances are in close proximity, or the substances are in areas prone to a number of hazards.

1.8.2.1 Life – Average Population

The figures showing hazard ratio versus average population density (see Figure 4) illustrate the effects of hazard reduction activities. There is an obvious cluster of substances associated with low population densities and low hazard ratios. The clustering of substances on the lower end of the x-axis is most likely representative of the increased controls placed on larger quantities or more dangerous substances, while clustering on the lower end of the y-axis represents effective planning that isolates hazardous substances from vulnerable elements.

Substances that have high hazard ratios and are stored in areas of high population densities are most often associated with areas prone to GS and Liq/GS hazards. Areas prone to FI most often present a lesser hazard as generally only low hazard ratio substances and low population densities are found in these areas.

1.8.2.2 Economy – Employment and Dwelling Densities

The figures showing hazard ratio versus employment density (see Figure 5) and dwelling density (see Figure 6) also illustrate the effects of hazard reduction activities. There is an obvious cluster of substances associated with low densities of these vulnerable elements and low hazard ratios. As with population densities, the clustering of substances on the lower end of the x-axis is most likely representative of the increased controls placed on larger quantities or more dangerous substances, while clustering on the lower end of the y-axis represents effective planning that isolates hazardous substances from vulnerable elements.

Substances that have high hazard ratios and are stored in areas of high employment or dwelling densities are most often associated with areas prone to GS and Liq/GS hazards. Areas prone to FI most often present a lesser hazard as generally only low hazard ratio substances and low population densities are found in these areas.

These results suggest that the risk to the economy from a hazardous substance release bought on by a natural hazard will be greatest in an earthquake. There are more hazardous substances stored in areas prone to liquefaction and/or amplified ground shaking, and these substances have higher hazard ratios therefore posing a greater hazard. The hazard is maximised for those substances located in areas prone to Liq/GS as the likelihood of damage is greater due to the combined hazard.

The impacts of a release will affect the areas of comparatively high population, employment and dwelling density in an earthquake, which are the elements considered most vulnerable in this study.

1.8.2.3 Emergency Response and Recovery – Priority Transport Routes, Schools, Emergency Services

Hazardous substances stored in close proximity to emergency response and recovery elements are predominantly located in areas prone to GS or GS/Liq. Consequently, earthquakes are likely to cause the greatest hazard to the elements included in this study.

Emergency services and schools have only a few substances around them and the hazard ratios are low in most cases. Sensitive environments have many substances in their vicinity, some of which have very high hazard ratios. Priority transport routes also have many substances in the vicinity but the hazard ratios are slightly lower. Priority transport routes have the smallest buffer but have some of the highest incidence of co-location. The other elements all examine the substances within 300m of their location. This suggests that the lowest risk of being affected by a release is associated with emergency services and schools as there are only a few substances, with low hazard ratios located within quite large areas surrounding them. Priority transport routes are less well protected.

1.8.2.4 Environment – Significant Natural Environments

Hazardous substances stored in close proximity to emergency response and recovery elements are mostly located in areas prone to GS or GS/Liq. Consequently, earthquakes are likely to cause the greatest hazard to the elements included in this study. Significant natural environments are poorly protected, with many high hazard ratio substances stored nearby .

It is most likely that sensitive environments are more at risk due to lower values placed on environmental features than on features such as schools, hospitals and fire stations. Priority transport routes are at higher risk probably due to the relatively short time that has elapsed since their identification. Also, the proximity of major arterial routes would be identified as important when locating an industrial facility.

1.8.3 Semi-Quantitative Assessment of Risk

1.8.3.1 Individual Substances

The average vulnerability value for each substance is in the region of 5-10, which equates to an average daily population of 5-10 people per hectare. This equates to areas with quite high employment density (e.g. densities such as those found in areas of East Tamaki, Wiri) or moderate residential densities (e.g. densities such as those found in areas of Medowbank, Avondale, Takanini). This indicates that most substances are located in areas of significant numbers of people.

1.8.3.2 Cumulative Risk

Many substances in areas prone to hazards are located in the vicinity of other substances. This is demonstrated by the large number of substances identified for use in this study (975), and the significantly lower number of 500m x 500m squares which were identified as containing these substances (323).

This also suggests a clustering of substances into only 323 of the 22,375 500m x 500m squares in the region. This suggests that hazardous substances are stored together in clusters, sometimes containing the most hazardous substances and quantities in the region. This would be expected as a result of zoning areas where substances are subject to less stringent controls.

1.9 Data Gap Analysis

1.9.1 Data Completeness

There are little complete and accurate data on hazardous substances in the Auckland Region. This is due to the fact that there are many different organisations, working under different legislative drivers, for different purposes, with different interpretations, tools, and resources for collecting, recording and monitoring hazardous substance storage information. Consequently there are large variations in the detail of data. At least part of the reason that the HSNO Act was introduced was probably to simplify the myriad of legislation surrounding hazardous substance management.

The most complete and comprehensive data used for this study has been obtained from dangerous goods licences and the OSH Explosives Database. Other sources contained inadequate data for this study (i.e. lacking information on quantities, classes). Consequently, this study is biased towards those substances that are identified as either dangerous goods of explosives. There is a distinct under-representation of toxic and eco-toxic substances in this study.

In addition, it is also unlikely that even the best dangerous goods licensing database contains a completely accurate record of dangerous goods stored in a given area. It is widely recognised that there is incomplete compliance with the Dangerous Goods Act. However, this is the best available information available. Substances that are not identified in the dangerous goods databases are unlikely to have a type or quantity that a release would necessitate a regional response.

Some difficulties were encountered in correlating dangerous goods information with UN classes, as sometimes the class of substances was not provided. When this situation occurred, a conservative approach was taken and the substance was considered to be the most hazardous of the options available.

It should be recognised that the suitability of the data for this analysis (as presented in Table 1) does not necessarily represent the overall quality of the data. In fact the most complete and up-to-date data may have been from Waitakere City as they had recently undertaken a broad survey of hazardous substances as part of their 'cleaner production' scheme. Unfortunately, many of the fields required for this study were incomplete, as the information gathered did not always include UN Class.

1.9.2 Information on Areas Prone to Hazards

The limited number of areas identified as prone to hazards was apparent. Without a better spatial understanding of areas prone to hazards there is limited ability to undertake GIS based investigations of risk. The areas identified as prone to hazards are based on dated research and cover only a few of the hazards present in the region. Some other areas prone to hazards that could be identified in the future include fault rupture zones, areas prone to coastal hazards (coastal erosion, coastal flooding, tsunami inundation, sea level rise), wildfire hazard, and areas prone to land instability.

The identified areas prone to hazards represent different return periods and thus a variable hazard. The areas prone to flooding delineate the extent of inundation in a 1 in 100 year flood event. The areas prone to earthquake hazards identify soils that are more likely to liquefy or be subject to amplified ground shaking in a 1 in 2000 year earthquake event. Assumptions used in this study were made based on the relationship between the hazard identified for each area and the likelihood of release. This assumption is tenuous and could be greatly improved if research was undertaken on the actual relationship between the area prone to hazards and the probability of rupture.

1.9.3 Location Information

None of the data sources provided location information more accurately than to land parcels, which creates limitations for analysis. Potentially, hazardous substance storage locations could be significantly different to where they are located for the purposes of this study. This is more likely to occur where a substance is stored on a large property rather than a small property. Some sites, such as large industrial complexes, are large land parcels and so would be more likely to be affected by this situation. These large complexes are also the most likely to store large quantities of hazardous substances. Site-specific studies could resolve these accuracy issues.

The inaccurate information on hazardous substance storage locations has limited the ability of this study to assess the distances from substances where effects are likely to occur. This type of analysis is also limited due to the unavailability of data that would be required for such an analysis (see Section 1.2). If all hazardous substances were recorded using accurate co-ordinates the analysis could incorporate all substances in the region, rather than just those considered 'regionally significant', without using an address matching system, which required a considerable time investment.

1.9.4 Vulnerability

Much more work could be undertaken assessing the vulnerability of the Auckland Region. There are many aspects of vulnerability that could be refined for further GIS-based risk assessments and incorporated into more complete risk assessments. Better information on hazardous substances could also improve assessment of the vulnerability (i.e. weighting the substances with toxic effects more heavily when assessing impacts on the environment).

1.9.5 Risk Assessment

Several approaches to investigate risk were used in this study. The first, a statistical analysis of the regions hazardous substance distribution, was largely successful. Improvements to the datasets that were drawn together to undertake this analysis (i.e. areas prone to hazards and hazardous substance records) would lead to an improved result.

The second approach was also largely successful in establishing relationships between the relative hazard presented by substances and the density of some vulnerable elements of the community. Improvements would result from any improvements in the hazardous substance dataset, areas prone to hazards, or refinements of the census data to smaller meshblocks.

The third approach used was a little coarse as it was only able to establish the number of substances that were located near the vulnerable elements addressed by the study. This gave a rough approximation to the risk posed to each vulnerable element. The weakness of this method is the inability to relate the zone around each substance to an actual 'area of likely effect'.

The forth method provided a rough estimate of overall risk. To better establish quantitative risk measurements, valuing needs to be undertaken so that risk values that fairly balance the value of life, the environment, infrastructure and economic costs can be determined.

1.10 Findings

Due to confidentiality agreements it is not possible to provide specific details of the exact location and extent of risk. This report only provides a general indication of the risk presented to the region. The confidential appendices provide some further details, but the intention is for the ARC to work further with territorial authorities in identifying the most critical industries.

This study was limited by data availability. More complete and accurate data would allow a more robust investigation, however the findings do provide some indication of where site-specific investigations may be warranted.

- The number of hazardous substances and the location of substances with high hazard ratios in each area broadly reflect the population of each territorial authority. Exceptions are North Shore City, which has a low number of hazardous substances stored with respect to its population, and the Rodney District with a high number of hazardous substances. It is unclear how much of this result is due to differences between the various recording methods.
- Relatively more planning seems to have taken place to avoid locating hazardous substances in areas prone to flooding than in areas prone to liquefaction and amplified ground shaking. It appears that little has been done to assess the potential impact from earthquakes on hazardous substance storage. This has resulted in increased vulnerability to the effects of an earthquake. In almost all cases there is greater vulnerability to earthquakes.
- Clearly thought has gone into locating hazardous substances away from areas of high population, employment and dwelling density. However, it is not clear whether this situation remains when extended to the cumulative effect of many substances stored in close proximity to one another. This demonstrates the effectiveness of current legislation surrounding dangerous goods management.
- However, this does not prove that risk is acceptable. It will be a decision that needs to be addressed by the dangerous goods inspector as to whether aspects of risk, such as the moderate population density surrounding the top hazardous substances in the region described in section 1.6.1, is appropriate.
- Earthquakes are likely to have the greatest effect on the emergency response and recovery elements assessed in this study indirectly through hazardous substance

release. Of the earthquake effects, amplified ground shaking is likely to affect more hazardous substances than liquefaction, although both of these hazards will affect many substances.

- Schools are generally not located in close proximity to hazardous substance that may be released resulting from a natural hazard. This suggests that their use in event of a natural disaster is unlikely to be impeded by hazardous substance releases. Schools not only show a high vulnerability due to the number of younger children, but also play important roles in the recovery of a community.
- Similarly, emergency services play an important role in the recovery of a community from a natural disaster. The exposure of emergency service facilities is low to this type of indirect hazard. This finding suggests that it will be unlikely emergency services will suffer extensive problems from such a hazard that could hinder rescue and recovery operations.
- Re-establishment of the priority transport routes described by the AELG report may be hindered due to hazardous substances release nearby. The impact is difficult to assess accurately at the level of this study, consequently this network is a potential candidate for site-specific investigations to more accurately determine the extent of problems associated with re-establishing these routes.
- Significant natural environments are also likely to be heavily impacted by hazardous substances release as a result of natural hazards. An earthquake is likely to affect the greatest number and most hazardous of the substances stored near significant natural environments. It appears that these environments have been considered very little when determining hazardous substance storage locations and so have been afforded little protection.

Recommendations

Summary

More accurate hazardous substance information needs to be collected including more accurate location data, quantity, and substance information. A more uniform approach to collecting the data would also be advantageous.

It may be possible to create a central repository that would house data in a consistent form for all agencies involved in managing hazardous substances.

The ARC needs to provide information to the territorial authorities to allow further site-specific investigations of those storage facilities identified by this study as high risk.

Greater spatial mapping of variations in risk posed by natural hazards need to be undertaken. Possibilities include fault rupture, coastal hazards (erosion, flooding, tsunami, sea level rise), wildfire and land instability.

Further investigations need to be undertaken into the relationship between hazard and likelihood of rupture of storage containers, vulnerability to different substances, and supporting research into the development of multi-hazard, multi-vulnerability risk analysis methods.

- Substantial improvements to the methodology could be made by recording the storage locations of hazardous substances more accurately than only to land parcels. Storage locations could be recorded in map co-ordinates through the use of handheld GPS receivers. The improved location information would assist in planning, risk assessment and potentially assist response agencies such as the Fire Service in the event of a fire.

- Differences between the databases that were used in this project caused varying degrees of accuracy in the final combined database. A uniform structure for constituent databases would aid these types of studies. Additional information in some of the databases would allow more comprehensive analysis of risk (i.e. storage type, substance names and UN or HFSP class, volumes of substances to be recorded in consistent units for the same substances or classes).It appears that, under the new HSNO legislation, information on hazardous substances will become more fragmented, as more organisations will be charged with administering the act. Some of the difficulties experienced gathering information for this study were due to variations between agencies and territorial authorities methods of collecting and recording information. To introduce further fragmentation would likely make such a task even more onerous, if even possible.

  There are opportunities for some of the databases that exist to be improved in line with the more advanced databases that were used. All face similar issues of keeping information current and regularly monitored. This also provides many opportunities for the pooling of resources to more efficiently fulfil the requirements of the various legislative drivers.

In light of the HSNO legislation presenting councils with a choice of whether dangerous goods information will continue to be collected, there is the possibility that this information will cease to be collected. It is suggested there is an ongoing need to capture this data. As such, there should be ongoing liaison with territorial authorities dangerous goods inspectors and ERMA to ensure that information on where hazardous substances are stored will continue to be collected.

- There is the potential for the initiation of a project that will bring together information on hazardous substances in a central repository. This could be implemented through the Internet. This database could then be used by all agencies that administer the HSNO Act, and perhaps agencies that would benefit from the information for safety or other reasons (such as the Fire Service when responding to fires where hazardous substances are present). Such a database would need to be administered by a single agency that would then provide a password access to the other partners. The data would need to be subject to quality control by either the data providers or the database holders.

  Under the current environment of change, it is advised that such a project be only investigated in a conceptual stage. There are many issues around the recording of hazardous substance information that will need to be resolved before such an ambitious project could be realistically advanced.

  This proposed central database would be the ideal continuation of the database that has been established for this project. The current database provides a 'snapshot' of the current situation, useful given the potential loss of this data, but an ongoing real-time database would be a highly useful tool for many agencies involved in the safe management of hazardous substances.

- Due to the restrictions placed on hazardous substance information that has been provided there has been a limited opportunity to present the findings of this research for wide dissemination. It is intended that conclusions from the research presented in this report and the confidential appendices will be dealt with through communication with individual territorial authorities.

  The limitations on the research will prevent the results being accepted without undertaking site investigation of those sites that are identified as presenting the highest risk. Such investigations are likely to be undertaken by the territorial authorities as they see fit, with assistance from the ARC if required.

- The areas prone to hazards used in this study are dated and cover very few of the hazards present in the region. Some other areas prone to hazards that could be developed include fault rupture zones, areas prone to coastal hazards (coastal erosion, coastal flooding, tsunami inundation, sea level rise), wildfire hazard, and areas prone to land instability.

- Assumptions had to be made for this study on the relationship between the hazard identified for each areas and the likelihood of a rupture. The assumption made is tenuous and would be greatly improved if research were undertaken on the actual relationship between the areas prone to hazards and the probability of rupture.
- Further work needs to be undertaken assessing vulnerable elements in order to increase the range and number of vulnerable elements considered and allow a better understanding of the degree of vulnerability to different types of substances (toxic vs explosion vs gas vs liquid).
- Further research needs to be undertaken into the relative value placed on life vs significant natural environments vs emergency response and recovery elements vs economy. This can be done by supporting existing research into the development of multi-hazard, multi-vulnerability risk assessment techniques.

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Appendix 1 – HFSP Threshold Adjustment

CLASSIFICATION INFORMATION		HFSP INFORMATION					EMERGENCY PLANNING THRESHOLD SINGLE SUBSTANCE
HSNO category	UN Class equivalent	Hazard level	Units (Tonnes or m^3)	Base Quantity			
				Fire/ Explosion	Human Health	Environment	
Explosiveness							
1.1	1.1	High	t	0.1	-	-	1
1.2	1.2	Medium	t	1	-	-	10
1.3	1.3	Low	t	3	-	-	30
Flammable gases							
2.1A+B (LPG)	2.1 (LPG)	Medium	t	30	-	-	10
2.1A+B (excl. LPG)	2.1 (excl. LPG)	High	m^3	10,000	-	-	3000
Flammable liquids							
3B	3 PGI	High	t	10	-	-	100
3A	3 PGII	High	t	10	-	-	100
3C	3 PGIII	Medium	t	30	-	-	300
3D	Combustible Liquids	Low	t	100	-	-	N/A
Flammable solids							
4.1 (all categories)	4.1	Medium	t	10	-	-	100
4.2 (all categories)	4.2	High	t	1	-	-	10
4.3 (all categories)	4.3	High	t	1	-	-	10
Oxidising gases, liquids and solids							
5.1 (all categories)	5.1	Medium	t	10	-	-	100
5.1 (all categories)	5.1	Medium	m^3	10,000	-	-	3000
5.2 (all categories)	5.2	High	t	1	-	-	10
Toxic gases, liquids and solids							
6.1A	6.1 PGI	High	t	-	0.5	-	5
6.1A	2.3 PGI	High	t	-	0.5	-	5
6.1B	6.1 PGII	High	t	-	0.5	-	5
6.1B	2.3 PGII	High	m^3	-	30	-	10
6.1C	6.1 PGIII	Medium	t	-	10	-	100
6.1C	2.3 PGIII	Medium	m^3	-	50	-	15
6.7-6.9 (chronic toxicity categories)	OECD	Medium	t	-	10	-	100

6.1D		Low	t	-	30	-	300
6.1D		Low	m^3	-	500	-	150
Corrosive gases, liquids and solids							
(8A) 6.3-6.4 (corrosives, all categories)	8	Medium	t	-	10	-	100
Ecotoxic gases, liquids and solids							
9.1 A - 9.4 A	(OECD 1)	High	t	-	-	1	10
9.1 A - 9.4 A	(OECD 1)	High	m^3	-	-	30	10
9.1B - 9.4 B	(OECD 2)	Medium	t	-	-	30	300
9.1B - 9.4 B	(OECD 2)	Medium	m^3	-	-	50	15
9.1C - 9.4 C	(OECD 3)	Low	t	-	-	100	N/A
9.1C - 9.4 C	(OECD 3)	Low	m^3	-	-	500	150

Appendix 2 – Methodology and Equations

Definitions

Each of these values are defined by equations listed below. However, the following section contains verbal descriptions of each.

Risk – The chance of something happening that will have an impact upon objectives. It is measured in terms of consequences and likelihood (AS/NZ 4360:1999 Risk Management)

Hazard – A source of potential harm or a situation with a potential to cause loss (AS/NZ 4360:1999 Risk Management)

Vulnerability – Susceptibility and resilience of the community and environment to hazards (Disaster Risk Management Guide: A how to manual for local government)

Potential for Release – Probability of release occurring as the result of a hazard event

Likelihood of hazard occurring – a qualitative description of probability or frequency (AS/NZ 4360:1999 Risk Management)

Likelihood of Rupture due to hazard event – The likelihood of a rupture event, measured by the ratio of specific events or outcomes to the total number of possible events or outcomes. Probability is expressed as a number between 0 and 1, with 0 indicating an impossible event and 1 indicating an event is certain.

Hazard Ratio - A ratio between the quantity of a type of hazardous substance and its HFSP threshold.

Quantity of Substance – Quantity of a hazardous substance being stored. This value is measured in appropriate units for the substance e.g. l, kg.

HFSP Baseline Threshold – Hazardous Facilities Screening Procedure

Average Population Density – Day and night-time populations combined within each meshblock are used to calculate the population per hectare within that meshblock.

Equations

Hazard Ratio = Quantity of Substance / (HFSP baseline threshold x 10) (1)

Risk = Hazard x Vulnerability (2)

Hazard Value = Hazard Ratio x Potential for Release (3)

Risk = (Hazard ratio x potential for release) x Vulnerability (4)

Potential for release = Likelihood of hazard occurring x likelihood of rupture due to the hazard event (5)

Risk = (Hazard ratio x number of potential hazards) x Vulnerability (6)

Risk = (Hazard ratio x number of potential hazards) x average population density (7)

Calculation Examples

e.g.1 Small volume of medium hazard substance stored in an area prone to amplified ground shaking

Quantity of Substance = 50

HFSP baseline threshold = 30

Likelihood of hazard occurring = 0.0347

Likelihood of rupture due to hazard event = 1

Average population density = 50

Hazard Ratio = 50 / (30 x 10)

= 0.1667

Hazard Value = 0.1667 x (0.0347 x 1)

= 0.0058

Risk = 0.0058 x 50

= 0.289

e.g.2 Significant volume of medium hazardous substance stored in areas prone to amplified ground shaking, liquefaction and flooding

Quantity of Substance = 2000

HFSP baseline threshold = 30

Likelihood of hazard occurring = 0.0347

Likelihood of rupture due to hazard event = 3

Average population density = 53

Hazard Ratio = 2000 / (10 x 10)

= 20

Hazard Value = 20 x (0.0347 x 3)

= 2.082

Risk = 2.082 x 50

= 104.1