REPORT

Hawke Bay Coastal Strategy

Coastal Risk Assessment

Prepared for
Hawke's Bay Regional Council

Prepared by
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Date
May 2016

Job Number
20514.006.v5

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Distribution:

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Executive summary

Purpose

Hawke's Bay Regional Council (HBRC), Hastings District Council (HDC) and Napier City Council (NCC) are working together to develop a strategy for managing, or mitigating, coastal hazard risks along the Hawke Bay shoreline from Tangoio to Clifton to make a more resilient community.

This report provides the results of a regional scale coastal hazard risk assessment using the results of a coastal hazard assessment (reported separately). The hazards considered for this assessment are:

- Coastal inundation (overtopping and sea level rise) with 10%, 1% and 0.5% Annual Exceedance Probability (AEP) scenarios for the present day, 2065 and 2120. This corresponds to a 10 year, 100 year and 200 year return period event.
- Tsunami (modelled by HBRC) for 3 m, 5 m and 10 m which, based on the GNS most recent tsunami modelling represents 0.5%, 0.13% and .025% Annual Exceedence Probability (AEP) for the present day coinciding with Mean High Water Springs (MHWS). This corresponds to a 200 year, 750 year and 4000 year return period event.
- Coastal erosion (storm cut, trends, and effects of sea level rise) for 66%, 33%, 5% and 1% likelihoods for the present day, 2065 and 2120.

Mapping units and elements at risk

The coastal area has been divided into 16 units (Refer Figure 3-1) to enable a relative comparison of risk and vulnerability. Elements at risk considered in this assessment include the resident population and economic, social, cultural and environmental/ecological assets. These elements at risk have been obtained from Council databases. It is noted that there is very limited information within the Council's data base on Māori sites of significance, but it is recognised that it is highly likely that there will be sites of significance along the coastline.

Exposure

Exposure to the hazard is measured solely by the extent of the hazard, so does not measure severity or scale of the hazard. However, this approach provides a total proportion of elements affected by each particular hazard and information on exposure has been presented in terms of human, economic, social, cultural and environmental/ecological assets to each particular hazard for present day, 2065 and 2120.

Exposure has been classified from low (0 to 30% exposure) to high (70% to 100% exposure). In terms of relative scale the tsunami hazard has a significantly greater exposure than erosion and coastal inundation. Coastal inundation has the next greatest exposure.

For Coastal Inundation exposure is generally low in the present day apart from the Ahuriri Lagoon (Area M) and the southern Hawke Bay (Areas J, K and L) where exposure is moderate. The exposure in most areas increases in 2065 and there are a greater number of moderate to high exposures at 2120. In terms of land use type, regional park land has high exposure, recreational land exposure is moderate and the remaining land use types have low exposure. Social and cultural items also have low exposures, but as noted above, it is likely that cultural items of significance, particularly to Māori, are under-represented.

For tsunami hazard, exposure is generally low for a 3 m tsunami for most of the areas apart from Westshore, Ahuriri and the Port of Napier (Areas D, E and F) where exposure is moderate to high. All mapping unit areas exposure is high for a 10 meter tsunami height apart from Whirinaki (Area B) and Tukituki (Area P) where exposure is moderate. This trend is observed for all elements at risk.

For coastal erosion exposure is generally low as it affects only the coastal margin. However, the exposure increases progressively with sea level rise, particularly at the northern and southern ends of the study area. The main land areas affected are recreation and rural residential land, although there is an increasing exposure to all elements at risk with increased sea level rise.

Risk assessment approach

The overall risk assessment examines "hazard x vulnerability" where vulnerability represents damages and losses. The risk assessment presents information in terms of losses and likelihood for each hazard. Risk has been categorized in human, economic, social/cultural and environmental losses for each hazard.

Risk assessment results

The summary of risk classification for tsunami (3 m, 5 m, 10 m), the 1%AEP coastal inundation at present day, 2065 and 2120 and P1% coastal erosion for the same time periods as the coastal inundation assessment are set out in Table 7-6. The results are shown in terms of effects on humans (fatalities and injuries), economic, social and cultural and environmental/ecological for 15 mapping areas (excluding the Port of Napier) using value bands ranging from negligible/none to very high. Appendix C provides the total losses for the three hazards in terms of land use.

The tsunami hazard risk within the Hawke Bay region for the events modelled is significantly greater than the coastal inundation and coastal erosion hazard in terms of all key elements – human, economic, social/cultural and environmental/ecological. Losses for coastal inundation are generally greater than for coastal erosion, but the range of values are of a similar order of magnitude for these two hazards.

Human losses

Due to the short warning time for a near field tsunami and the magnitude of the events predicted, the tsunami hazard poses the greatest risk to human loss of life and injury, with all tsunami events modelled potentially able to cause both loss of life and injury. A 10 m tsunami height will have greatest impact in the Napier City area due to the high population density and low lying land. Potential fatalities of up to 5,400 and injuries of up to 4,600 are estimated for the 10 m tsunami. Loss of life is anticipated to be very low for coastal inundation and erosion as it is expected that a combination of better forecasting, early warning systems and approaches to manage future sea level rise will be more effective for these hazards.

Economic losses

The risks are generally negligible-to-low for the 3 m tsunami, with only Westshore, Ahuriri and Haumoana/Te Awanga (Areas D, E and K) being at very low to low risk. Ahuriri, Marine Parade and Napier (Areas E, H and N) represent very high risk for the 10 m tsunami hazard, while the urban and residential areas along the shoreline have moderate risk during this event. Ahuriri (Area E) and at Haumoana/Te Awanga (Area K) there is a gradual increase in losses from the 3 m to 10 m tsunami event due to the low-lying nature of these areas. Along Marine Parade (Area H) and Napier (Area N) there is a slow increase in losses from the 3 m to 5 m tsunami but a significant increase in losses from the 5 m and 10 m tsunami as existing defences are inundated by the tsunami.

In the present day coastal inundation losses are low. The losses increase significantly for coastal inundation from 2065 (up to moderate) and 2120 (up to very high risk). The greatest increase in loss occurs along Ahuriri (Area E), Awatoto (Area I), East Clive (Area J) and Haumoana/Te Awanga (Area K). The East Clive and Haumoana/Te Awanga area includes small residential settlements and the Hastings water treatment plant and is flood prone. Losses increase significantly from 1% AEP to 0.5% AEP events. The land area classification indicates the rural and urban residential risk is more prominent in 2065 and 2120 for all scenarios.

In the present day the coastal erosion hazard risk is generally very low to low, with Pacific Beach (Area G)) and Haumoana/Te Awanga (Area K) being the most at risk. Westshore, East Clive and Haumoana/Te Awanga (Areas D, J and K) are increasingly vulnerable for future scenarios for erosion reaching very high economic losses in 2120 in areas D, J and high losses in Area K and B (Whirinaki). Urban and rural residence are highly at high risk for erosion hazard, with roading risk influencing area B.

Social and cultural losses

It is recognised that there are likely to be items of value that are not mapped or identified, so this information provides an indication of the values affected, but cannot be considered a comprehensive assessment of actual loss, but more as a proxy of loss. It is recommended that a process to identify social and cultural values be carried out to improve understanding of risk.

Based on the information available, churches, schools, archaeological and heritage items are highly vulnerable for tsunami hazard. They are also highly vulnerable for coastal inundation hazard, although with the exception of Clifton (Area L) the other areas are of low to moderate risk.

Westshore, Ahuriri and Pacific Beach (Areas D, E, and G) shows low to moderate losses for erosion, while Clifton (Area L) shows moderate to high losses.

Environmental Losses

The environmental impact for both tsunami and coastal inundation has moderate to very high losses in the land areas. There are no significant losses resulting from coastal erosion.

1 Introduction

1.1 Purpose

Hawke's Bay Regional Council (HBRC), Hastings District Council (HDC) and Napier City Council (NCC) have initiated the development of a strategy for managing or mitigating coastal hazard risks along the Hawke Bay shoreline from Tangoio to Clifton to make a more resilient community.

A regional coastal hazard assessment was carried out in 2004 (T+T, 2004) that identified areas of potential erosion hazard and inundation levels inclusive of sea level rise to 2100. The information contained within this report and subsequent refinement reports carried out between 2004 and 2011 informed the Hawke's Bay Regional Coastal Environment Plan made operative on 8 November, 2014.

There have been additional studies and investigations to increase the level of information and data to support future revisions of the coastal hazard areas. They have included additional information on waves and coastal processes as well as updated information of shoreline change through HBRC's ongoing monitoring work, tsunami effects (GNS, 2013) and climate change (IPCC, 2013) with significantly greater levels of sea level rise to consider compared to the 2004 report.

1.2 Scope of works

The study is to carry out a regional scale risk assessment to provide high level information on coastal hazards and the consequences of these hazards on key elements at risk. This is to both provide an understanding of the risks as they presently are expected and to provide a baseline for comparing alternative coastal management strategies.

The spatial extent of the study area is the open coast areas between Tangoio and Clifton.

Hazards considered for this assessment are:

- Coastal erosion (storm cut, trends, effects of sea level rise)
- Coastal inundation (storm surge, set-up, run-up, overtopping and sea level rise)
- Tsunami (modelled by HBRC).

1.3 Report outline

Two reports have been prepared; a coastal hazard assessment report and a risk assessment report. This report provides information on the risk assessment only based on hazard assessment.

1.4 Study limitations

Limitations and assumptions for this study include:

- Due to a combination of sea level rise and historic trends (linear trend) and storm events (probability) probabilistic assessment is not possible, apart from at specific points in time. Likelihood of occurrence can therefore be determined using statistical methods at particular points in time (i.e. present day, 2065 and 2120) with the probability of the shoreline reaching a particular position.
- Economic loss estimates are not likely to represent the actual costs of re-establishment of any assets lost resulting from a natural hazard event, but provide a means of assessing the relative effect of the hazards.
- No change to present costs are applied for future scenarios. It is a relative assessment of increased risk based on present day costs due to the increased extent of the hazard.

- Building asset information is compiled from a number of sources and is not accurate for site specific assessments. They provide information suitable for a regional scale, assessment and evaluation of risk.
- Asset values are provided by Council and are based on best available information at the time of development of the data base but they may not reflect present day costs or actual replacement costs.
- The present study provides the assessment of risk (hazard x vulnerability) for the situation as it currently is. No scenarios are included for different management options at this stage.
- The value of privately owned utilities including power, gas and telecommunications has not been included in this study as this information was not readily available. Non-rateable land has also not been accounted for.
- For cultural items it is recognised that we can only identify exposure and loss based on published information on what is known. It is likely that there are value items, particularly of archaeological/spiritual values, which are unknown and therefore, the loss assessment only provides an indication of value loss.

2 Methodology

Assessment of hazard, vulnerability and risk of extreme weather or geo-hazard events are essential in order to inform and implement appropriate adaptation/prevention/mitigation strategies. In this study the risk assessment has been proposed based on Alexander (2002) formula:

Total Risk=hazard ×vulnerability

Where vulnerability represents damages and loss of properties.

The physical and environmental components of vulnerability can be defined as the degree of loss due to the exposure (loss) of a component to a hazard and the likelihood of being affected by dangerous phenomena due to the location and physical conditions of elements that will sustain certain hazard impacts. The general approach for this study is set out in Figure 2-1 and a description of the various stages set out below.

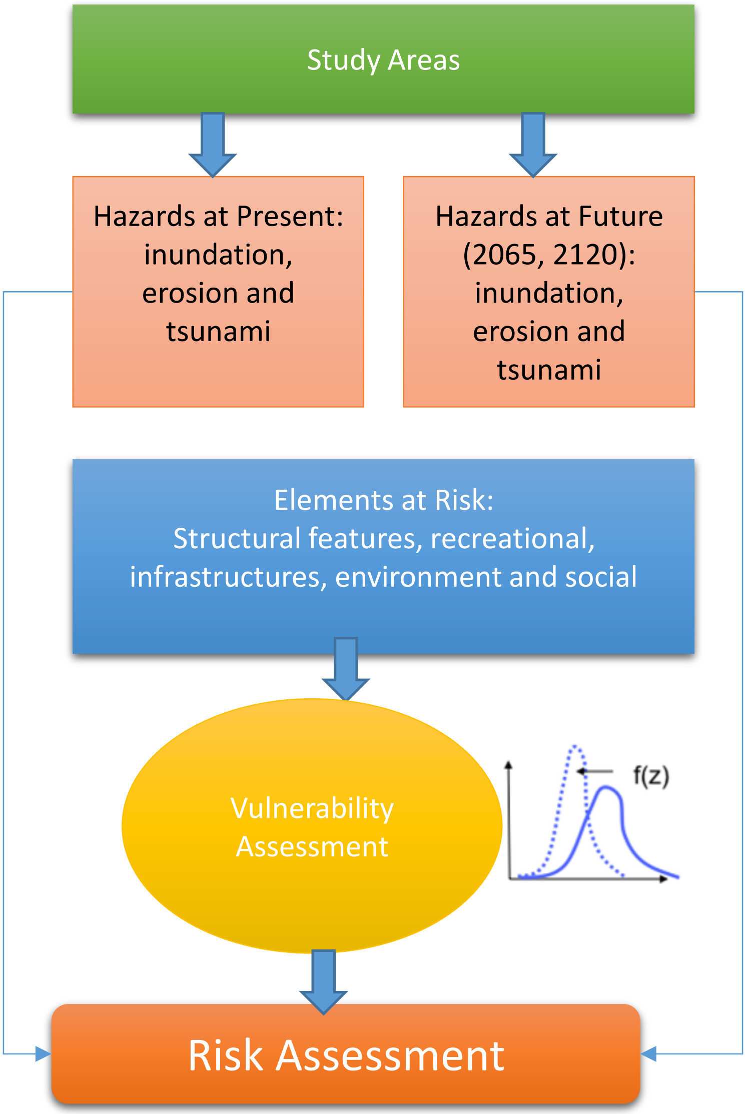

Figure 2-1: Conceptual Framework of overall methodology

3 Elements at risk

3.1 Study area mapping units

Mapping units along the coastal edge have been developed based on a combination of ward boundaries, land area units and topography to provide a coastal strip extending from Tangoio to Clifton. This enables a comparative assessment of potential risk by location. The resulting units are shown in Figure 3-1 and are identified from north to south alphanumerically from A to L along the coast and with four additional units (M-P) extending landward to incorporate land areas that may be affected by coastal inundation and tsunami. Spatial details of these units are summarised in Table B1 (Appendix B).

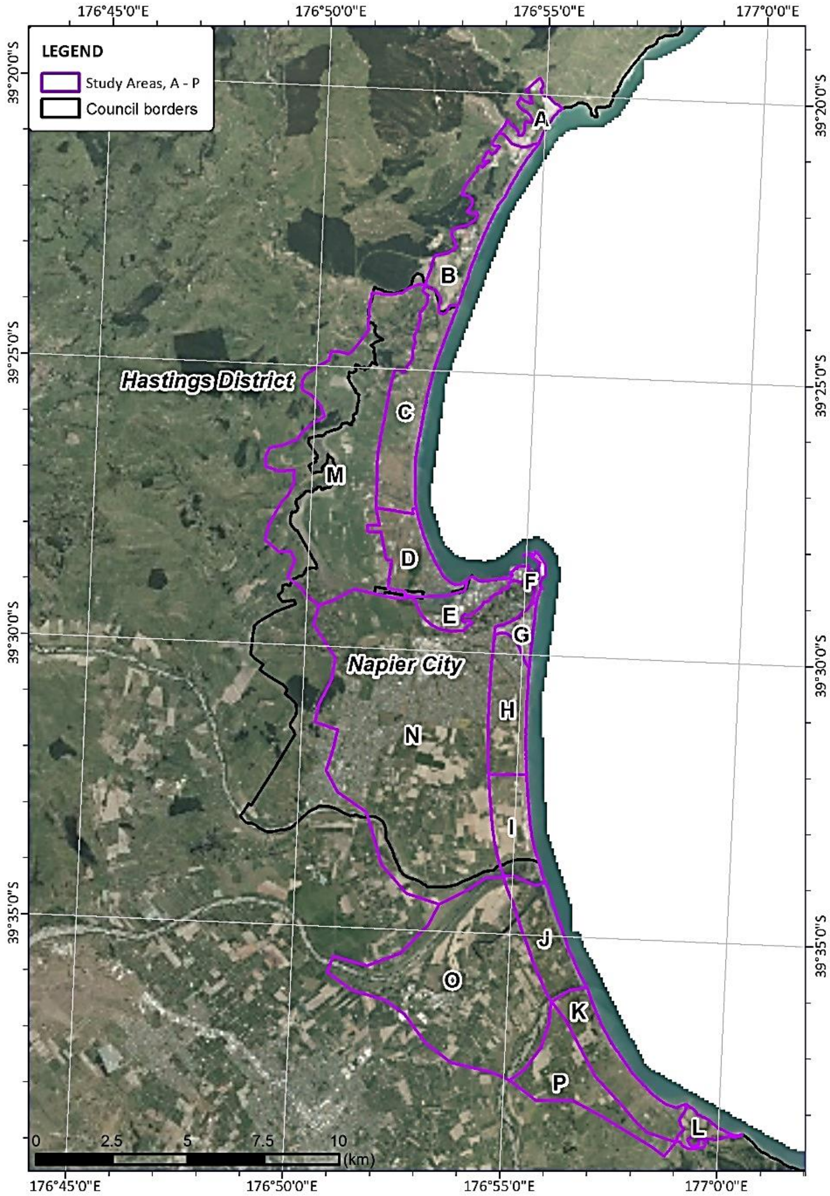

Figure 3-1 Mapping area boundaries

3.2 Key elements

Element-at-risk items identify the physical, economic, social or environmental units or systems which are at risk of being affected by the particular hazards. The vulnerability assessment provided quantified information on the following attributes:

Human – number of people affected

Economic – value of assets within area

Social/cultural – inventory of items within area

Environmental/ecological – area affected.

3.2.1 Human

According to the Statistics of New Zealand (2014) the population in Hastings and Napier district within the mapping area is 67,800 and 61,100. The population numbers in the coastal margin are shown in Figure 3-2. The total population in the coastal area (A to L) is 23,562 which is around 18% of the total population of Napier and Hastings. The population within the entire mapping area is 71,574, or more than 55% of the total population of Hastings and Napier.

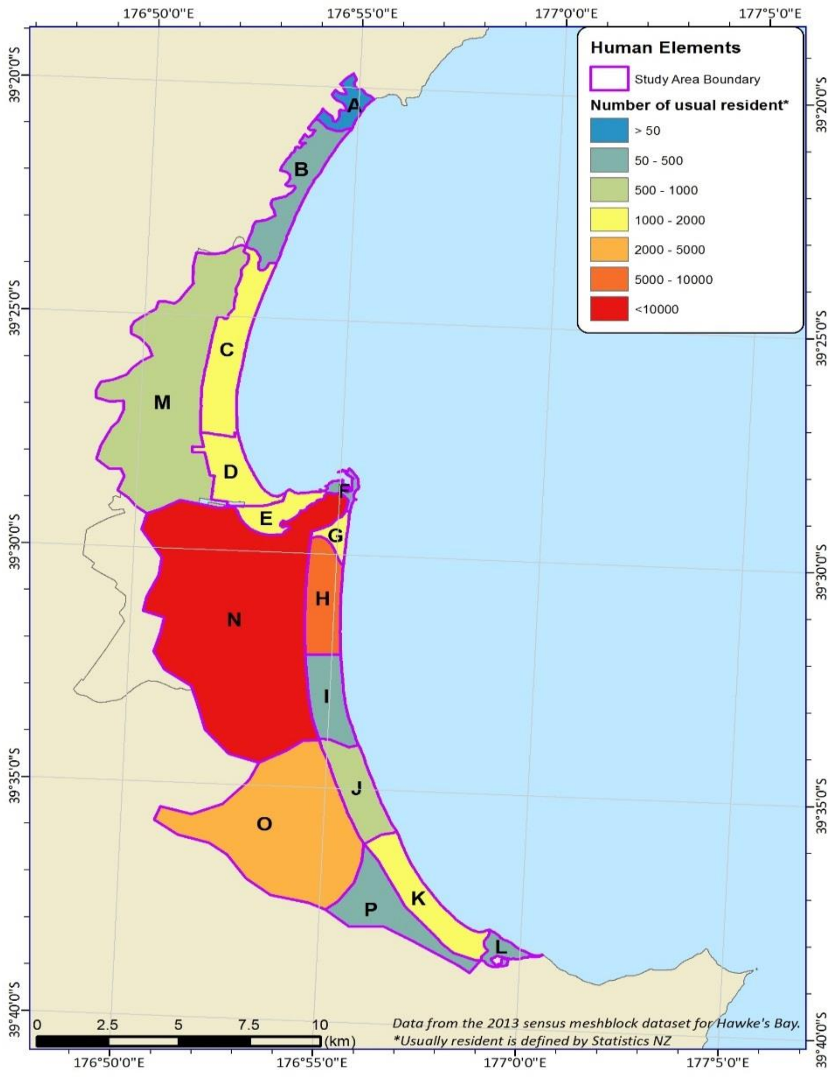

Figure 3-2: Population coverage in Hastings and Napier study areas

3.2.2 Economic assets

Given the large amount of assets, the focus has been on materiality to ensure that the key significant values are captured. The magnitude of values (particularly the capital value of land and buildings) mean that smaller assets (such as street lighting, urban parks and cell phone towers) generally make very little difference to the total damage value.

Assets have been assigned to the following categories for the analysis:

- Land and buildings
- State highways
- Local roads
- Water infrastructure (including potable water supply, wastewater and storm water networks)
- Rail infrastructure.

The source of specific elements at risk for these attributes are set out in Table 3-1 and summarised for each mapping area in Appendix B. Where possible property and land values have also been obtained from Council.

Table 3-1 Definition of economic elements at risk and data sources

Code	Description	Napier	Hastings
Res U	Residential – urban	Main residential, northern residential, Hardinge Road Residential, Marine Parade Character	Coastal residential, general residential, deferred general residential
Res R	Residential - rural	Rural residential, settlement, lifestyle character	Rural residential, plains residential
Com	Commercial	Inner city, art deco, fringe, suburban, large format, foreshore commercial, rural commercial	Central commercial, commercial services, central residential commercial, suburban, large format retail
Ind	Industrial	Main, suburban, west quay, marine industrial, port industrial, business park	Industrial 1 to 9
Util	Wastewater and stormwater utilities	Waste water pumping stations, storm water pumping stations, wastewater treatment	Wastewater treatment plant
Rec	Recreational	Foreshore reserve, marine parade recreation, reserve, sports park	Reserves
Rur	Rural/agricultural	Main rural	Rural, plains
AP	Airport	Airport and deferred airport zones	
EPCS	Electrical Power and communication Systems	National grid structure and grid line	
Road	Road Network	SH, Main and other roads, bridges	
Rail	Rail Network	Rail network – rail corridor and stations/infrastructure, bridges	

The proportion of land area occupied by these elements in terms of percentage of land area, is shown in Figure 3-3.

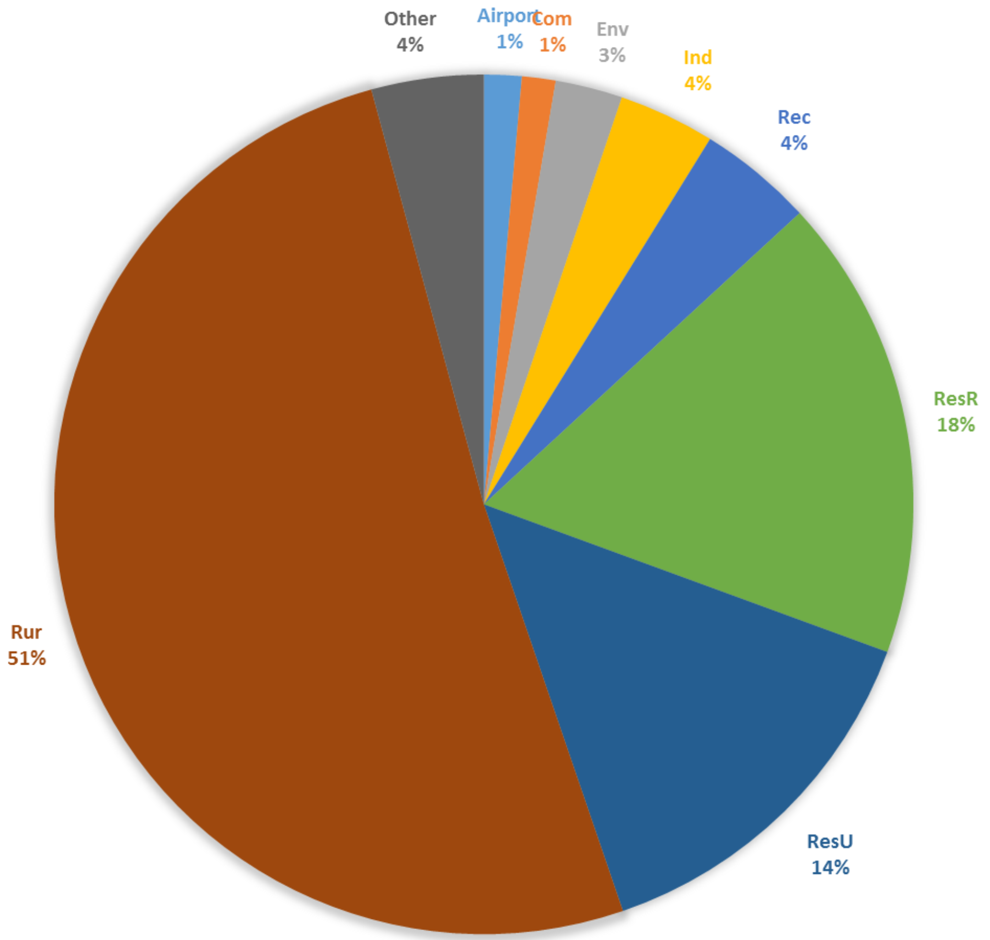

Figure 3-3 Combined land area distribution for all mapping units

This figure shows the largest land area is rural followed by rural residential and rural urban. Values for land and buildings have been taken from existing Council owned valuation databases based on land and improvement values. Additional costs for buildings for water infrastructure per connection have been calculated based on the replacement value of these assets from MHW (2015). Results of this assessment are included in Table 3-2. There is around 6% of the rural land with no values specified in the Council database and 5% of residential land had no cost values attributed to them.

Commercial and industrial land had values attributed to them in the Council data base. Port and Airport values were obtained from recent annual reports.

The segment marked 'Other' comprises road, rail and utilities. There is no readily available cost for the road and rail networks. A value for these assets has been made based on their replacement value, as shown in Table 3-3. Note that replacement values represents the cost of replacing the asset and does not include the cost of land and other non-depreciating assets. The value of land for these corridors has been estimated from average land values within each mapping unit. While it is recognised that after any disaster there will be a desire to rebuild, the full costs of rebuilding will typically be significantly greater than the replacement values shown in this report.

Around 2% of the recreational reserve land had no values attributed and 1% of the environmental land also had no economic value attributed.

The lack of economic value on some of the land areas identified means that the assessment does not provide a full assessment of direct losses. However it is sufficient as a base line for a regional risk assessment where comparative assessments are required.

Table 3-2 Estimate of replacement values of water services per connection (Source: MWH, 2015)

Asset type	Area	Connections (no.)	Length (m)	Length per connection (m)	Replacement value ($)	Value ($/m)	Value/ connection ($)
Water supply	Napier	25500	471000	18.5	$ 129,000,000	$ 274	$ 5,059
	Hastings	24222	484900	20.0	$ 145,000,000	$ 299	$ 5,986
Wastewater	Napier	24814	380000	15.3	$ 242,000,000	$ 637	$ 9,753
	Hastings	18706	396700	21.2	$ 358,000,000	$ 902	$ 19,138
Stormwater/ flood control	Napier	23413	226000	9.7	$ 164,000,000	$ 726	$ 7,005
	Hastings	24444	329700	13.5	$ 262,000,000	$ 795	$ 10,718
	Regional Council	47857	N/A	N/A	$ 162,000,000	N/A	$ 3,385
TOTAL per connection							$ 61,044

Table 3-3 Replacement values used to represent road and rail assets

Asset type	Area	Length (m)	Replacement value ($)	Value ($/km)
Local roads[1]	Napier	363	$ 327,000,000	$ 900,826
	Hastings	1635	$ 1,202,000,000	$ 735,168
Highways[2]	N/A	N/A	N/A	$ 3,000,000
Rail[2]	NZ	4128	$ 11,193,600,000	$ 2,711,628
Notes: 1 MWH (2015) 2 T+T estimate compiled from various sources 3 MOT (2005)				

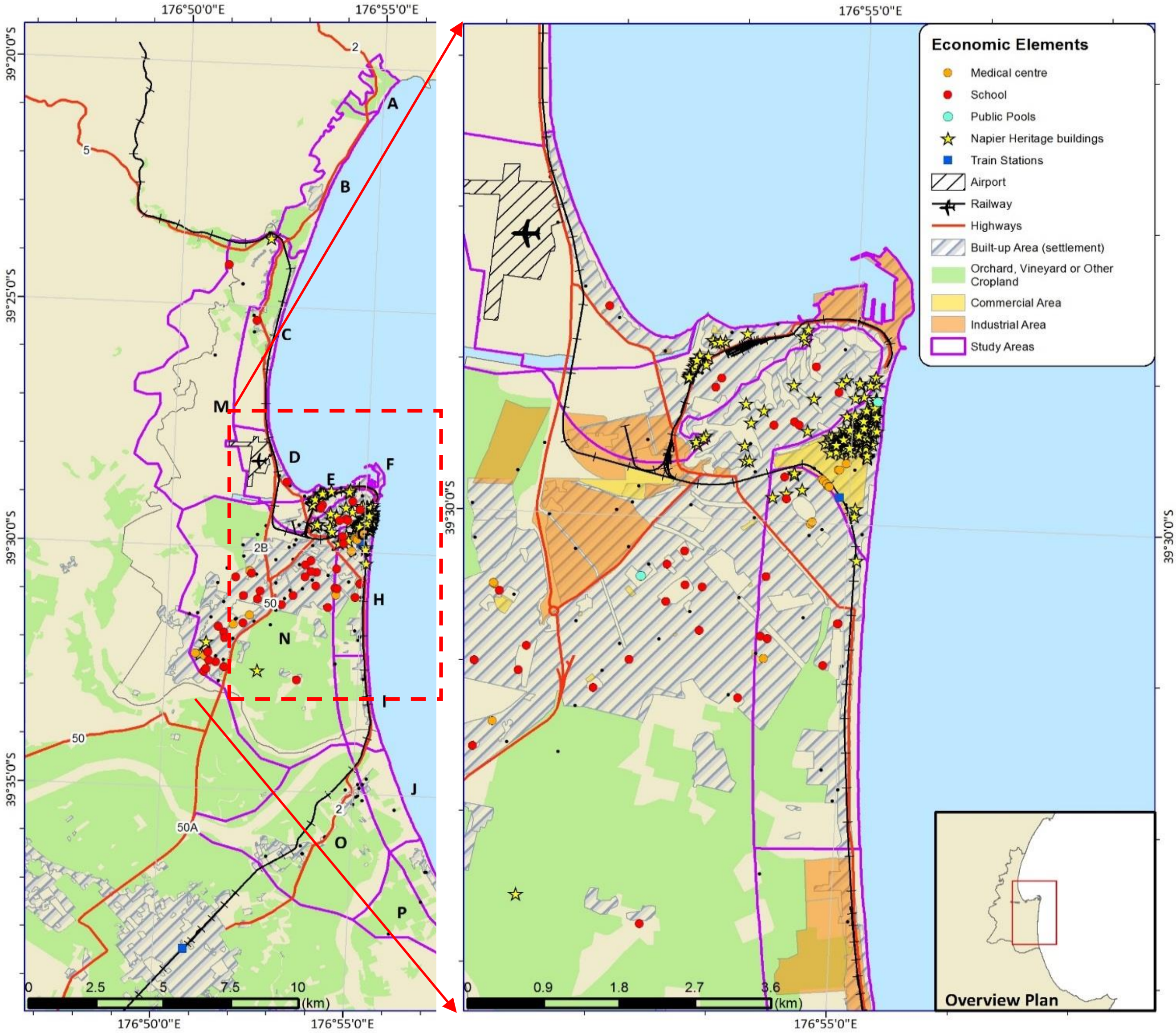

Figure 3-4: Economic assets in coastal environment of the Hastings and Napier study area

3.2.3 Environmental values

For the purpose of this study environmental value was linked to the ecological significance criteria outlined in Hastings and Napier's Plans. Key data sets/layers were obtained from Hastings and Napier councils and are summarized in Table 3-4 and in Table B1 (Appendix B). Figure 3-5 shows an overview of the environmental values locations. Specific elements at risk for these attributes are set out in Table 3-5.

Table 3-4 Environmental values received from HBRC and NCC

File name	source	Category	Values
HBRC_LCDB4	HBRC	Forest coverage	No
HBRC_Regional Parks_	HBRC	Regional park	No
Significant Conservation Area	HBRC	Conservation area	No
Notable_trees	NCC	Types of tress	No

Table 3-5 Definition of heritage elements at risk and data sources

Code	Description	Napier	Hastings
Env	Environment	Notable trees	Outstanding trees, outstanding natural features and landscapes, significant landscape character areas

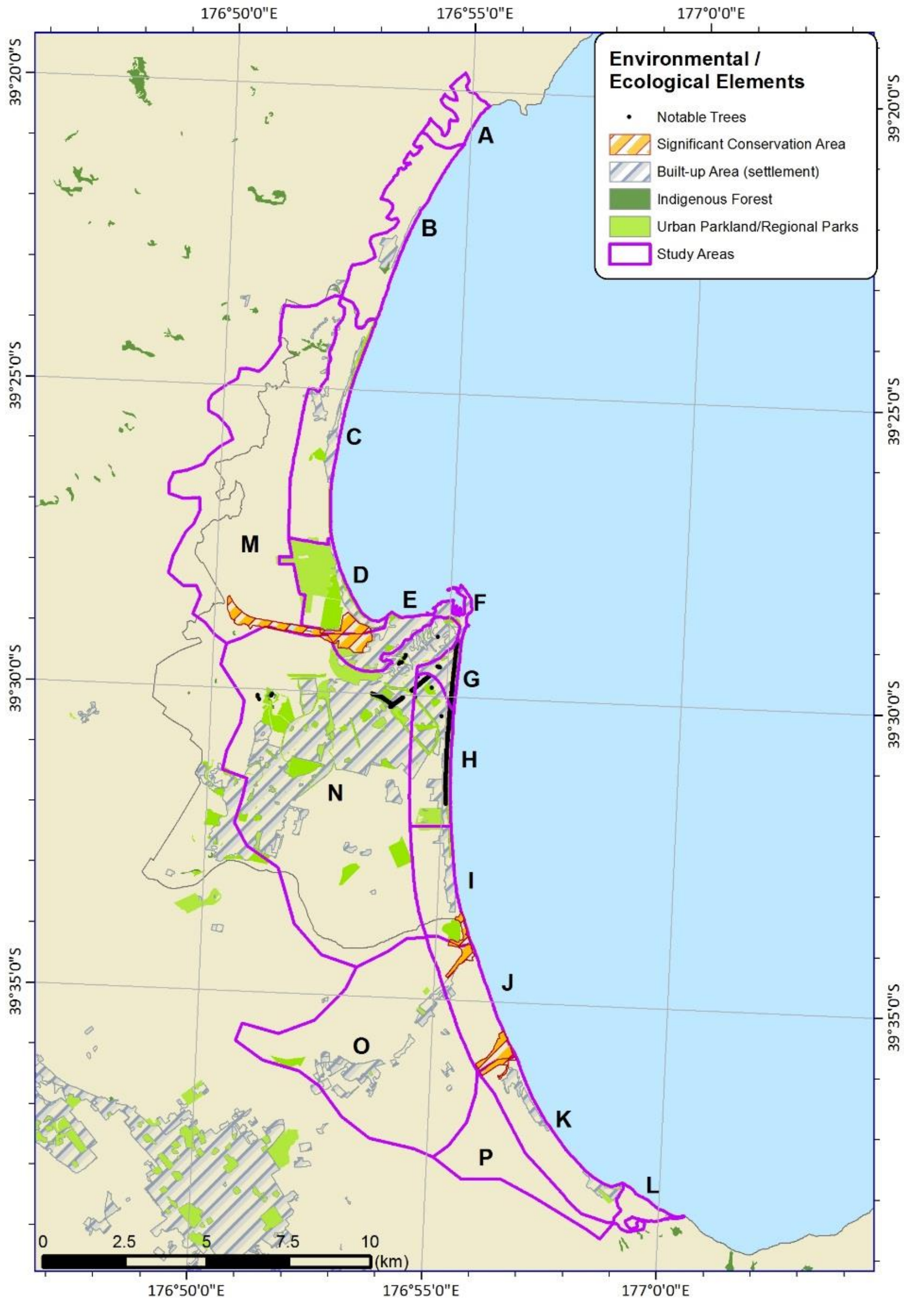

Figure 3-5: Location of identified environmental values

3.2.4 Cultural values

Cultural values by their nature are intrinsic values and therefore difficult to quantify. This study has comprised a review of sites and structures that could be impacted by the coastal hazards. Impacts on communities of different cultures have not been considered, as all cultures are assumed to be equally vulnerable to the impacts of sea level rise and this component is assessed under the social values assessment.

The cultural sites around the coastline and likely to be adversely affected by sea level rise are made up of sites of cultural significance to Māori, archaeological sites of all types, historical structures and places of cultural importance to all New Zealanders as identified through the District Plans. These sites form a part of our cultural heritage and provide valuable insight into the history of human occupation. Many sites are part of a broader cultural landscape as they showed the extent of communities living around the Hawke Bay coastline. These are shown in Figure 3-6 and in Table B1 (Appendix B). It is recognised that there are likely to be items of value that are not mapped or identified, so this information provides an indication of the values affected, but cannot be considered a comprehensive assessment of actual loss.

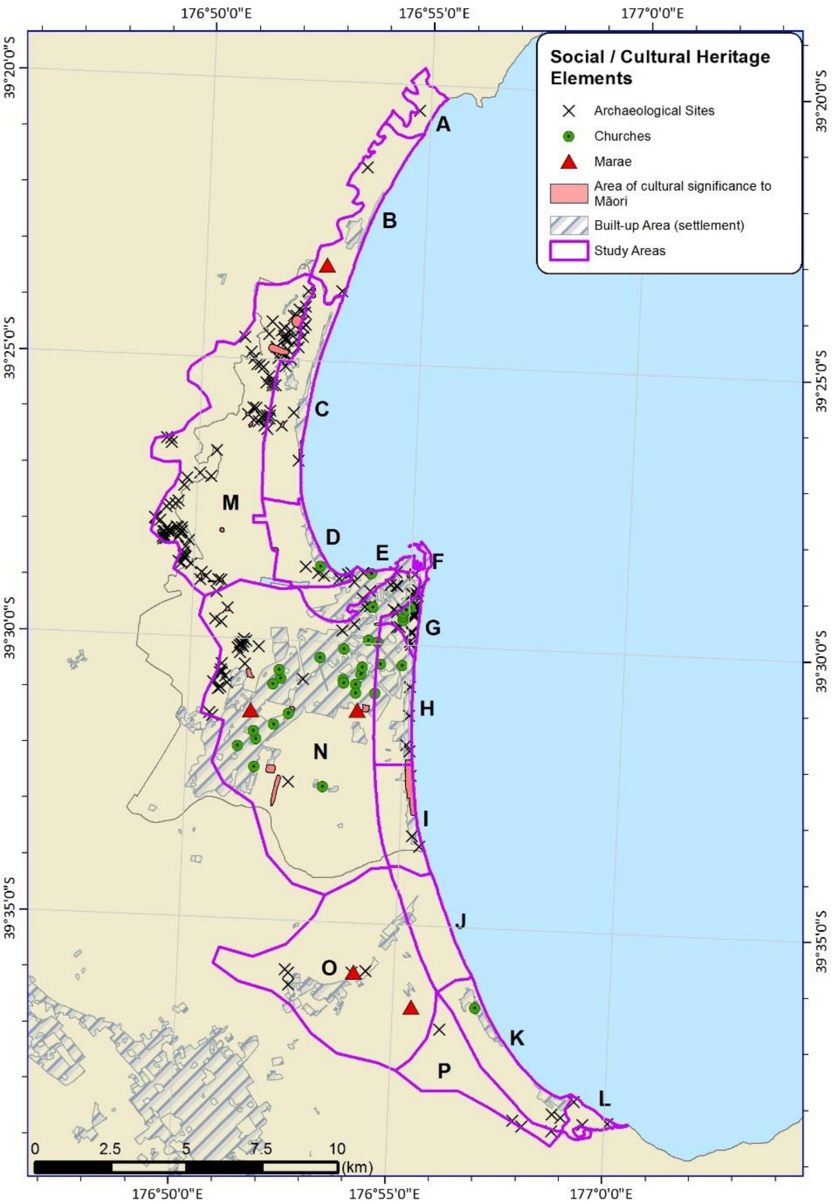

Figure 3-6: Cultural values in HBRC and NCC areas

Table 3-6 Definition of cultural and heritage elements at risk and data sources

Code	Description	Napier	Hastings
Her	Heritage	Archaeological sites, historical heritage buildings, areas of significance to Maori and Churches	Heritage features, Marae, Waahi Tapu sites, Churches

4 Hazards

Coastal hazards have been assessed and reported separately (T+T, 2015). The hazard assessment resulted in hazard maps for each erosion and coastal inundation hazard for a range of likelihoods for present day, 2065 and 2120. For the tsunami hazard only the effect of present day sea level has been considered for tsunami occurring at Mean High Water Springs (MHWS) as shown in Table 4-1. Not including consideration of sea level rise with tsunami is considered appropriate due to:

- the lower probability of the tsunami event compared to erosion and inundation
- the further reduction in likelihood possible with it coinciding at MHWS rather than Mean Sea Level
- The relatively large range in possible tsunami height considering the 16% and 84% confidence limits.

Table 4-1 Likelihoods used for generating hazard maps representation

Hazard	**Present day**	**2065**	**2120**
Erosion	1%, 5%, 33% and 66% likelihood of occurrence	1%, 5%, 33% and 66% likelihood of occurrence	1%, 5%, 33% and 66% likelihood of occurrence
Inundation	0.5%, 1% and 10% AEP	0.5%, 1% and 10% AEP	0.5%, 1% and 10% AEP
Tsunami	3 m, 5 m and 10 m have been estimated to be equivalent to 0.5%, 0.13% and 0.025% AEP or return period of 200, 750 and 4000 years.		

5 Exposure

Exposure to the hazard is measured solely by the extent of the hazard, so does not measure severity or scale of the hazard. This section quantifies the exposure to the hazards in terms of loss of area and the proportion of the elements at risk affected by the hazard. As there are some elements with no prescribed value, this approach provides a means of assessing relative impact on all the elements at risk. In broad terms exposure is considered very high above 90%, high where exposure is between 70% and 90%, moderate between 30% and 70% and low between 1% and 30%.

5.1 Inundation and tsunami

5.1.1 Inundation

Coastal Inundation exposure considered based on extreme water level for the 10%, 1% and 0.5% AEP events. Figure 5-1 shows land area affected by coastal inundation in terms of percentage of land area affected within the mapping units. Figure 5-2 summarizes the impact of the coastal inundation on total area by land use classification. Figure 5-3 shows the percentage of road and rail infrastructure exposed to inundation hazard. Further details on water assets (Figure 5-4), social and cultural assets (Figure 5-5) and significant trees and conservation areas (Figure 5-6).

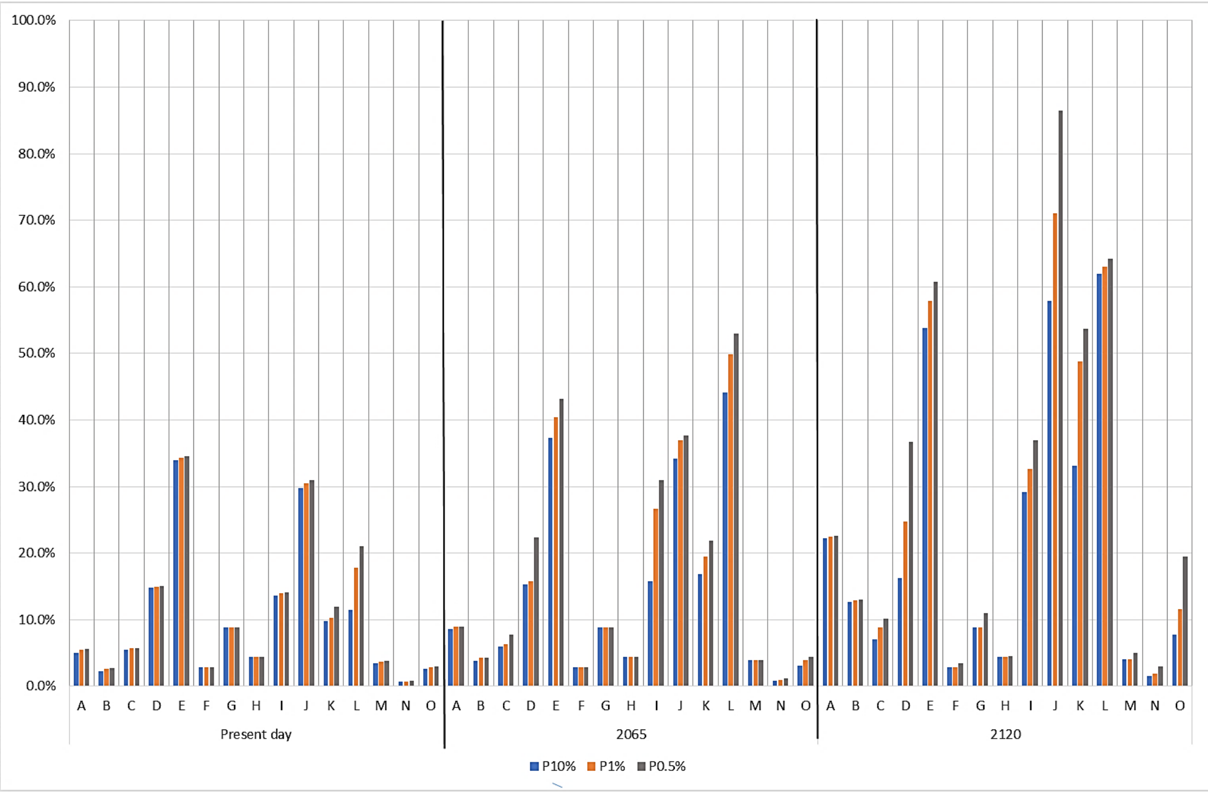

Figure 5-1: Percentage land area exposed to inundation by mapping unit

In the present day coastal inundation exposure is generally low, largely affecting the estuary (areas D, E) and areas adjacent to river mouths and the low lying areas in the southern Hawke Bay (areas I to L). With sea level rise the exposure to inundation increases to moderate to high levels in these areas (refer Figure 5-1). The main land use type affected in the present day is recreational reserve, residential rural land and environmental reserve land. However, sea level rise increases exposure significantly for other land uses (refer Figure 5-2) and for local road (Figure 5-3). Water asset exposure and exposure of social, cultural and environmental assets do not significantly change with increased sea level rise (refer Figure 5-4 to Figure 5-6). This suggests these assets are currently within the potential hazard areas and sea level rise will increase the severity, rather than the extent of the hazard.

Exposure levels tend to remain low for most elements at risk apart from recreational zoned land where exposure is moderate and for conservation and environmental zoned land where exposure is high.

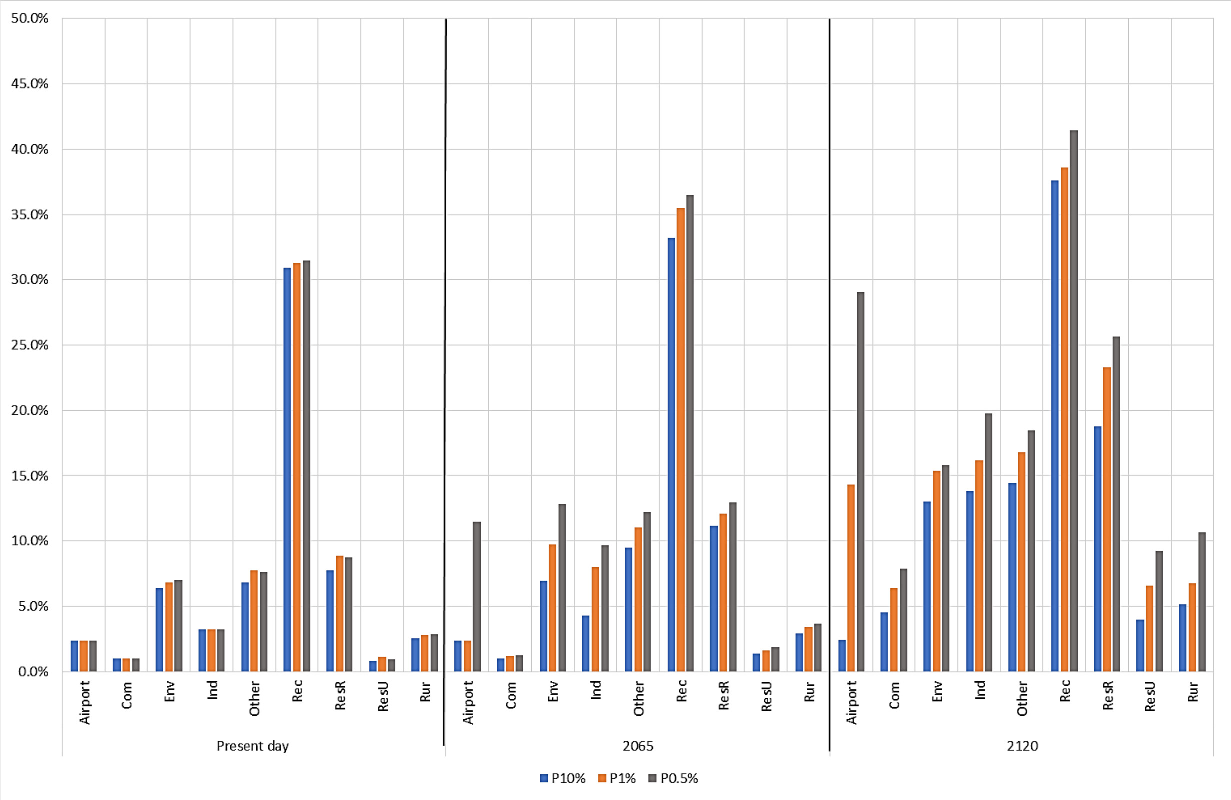

Figure 5-2: Percentage of land area exposed to inundation hazard by land areas classification

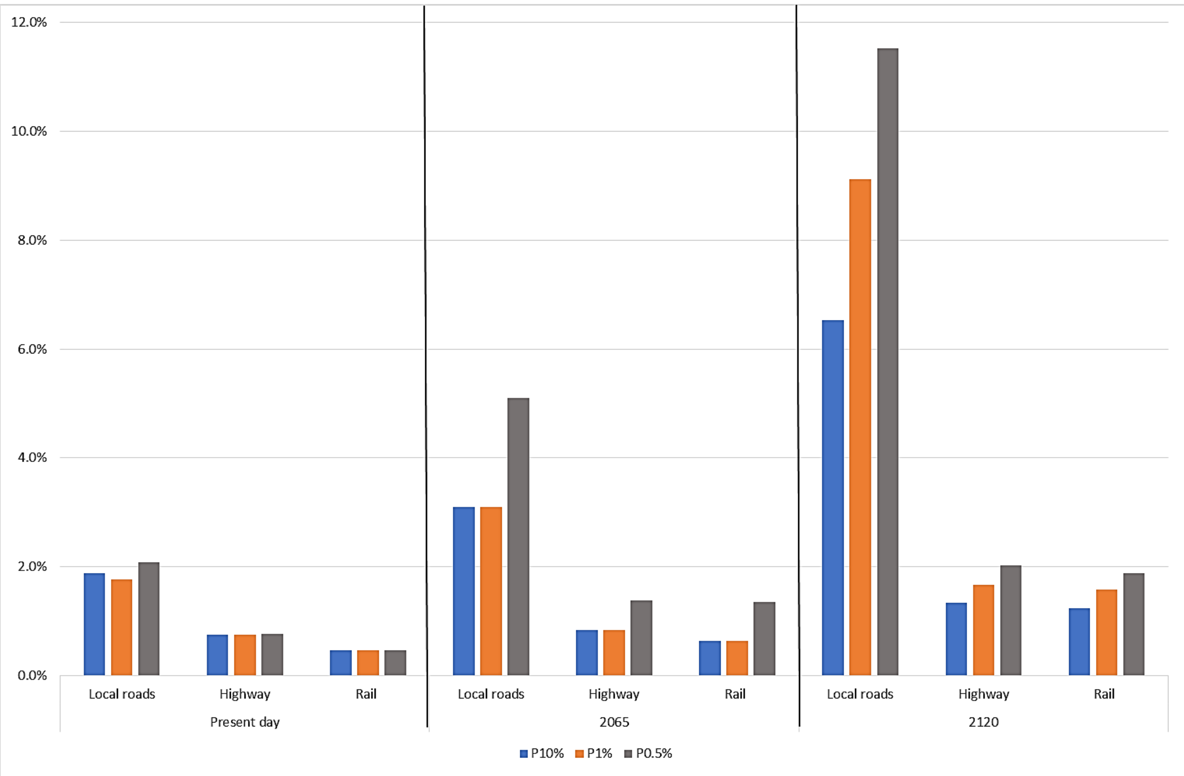

Figure 5-3: Percentage of road and rail infrastructure exposed to inundation hazard

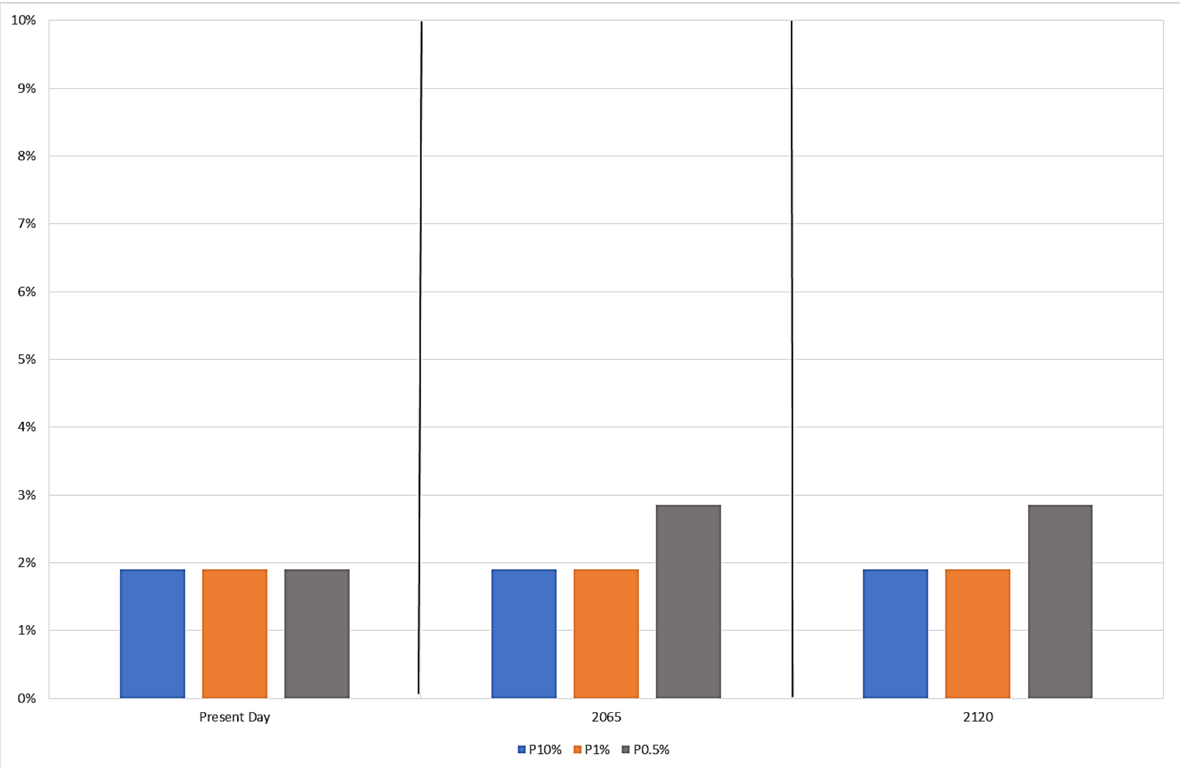

Figure 5-4: Percentage of water assets exposed to inundation hazard

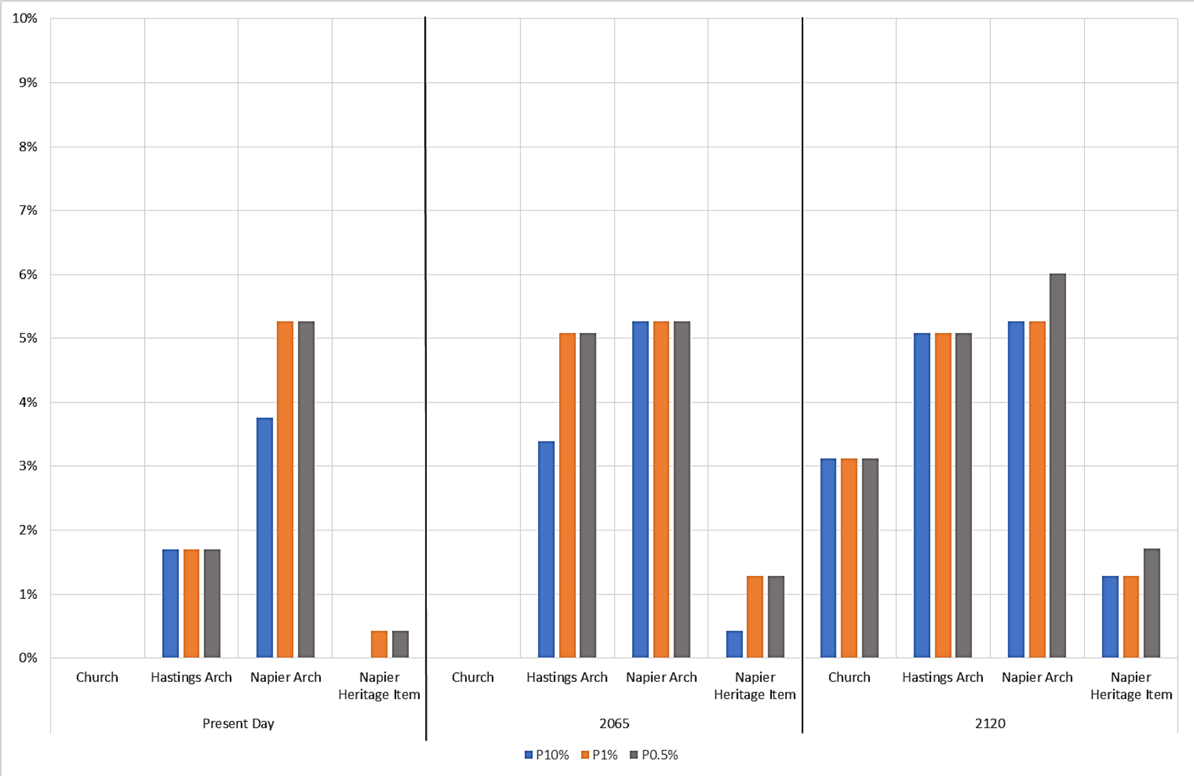

Figure 5-5: Percentage of social and cultural assets exposed to inundation hazard

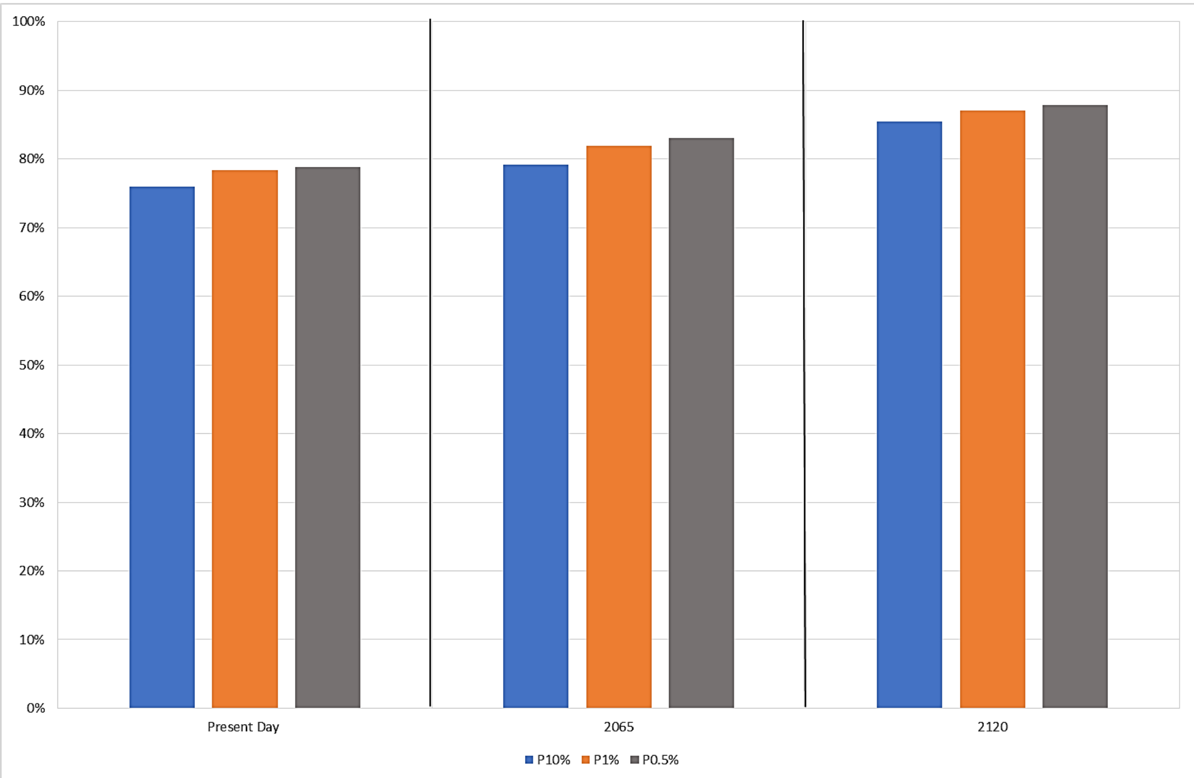

Figure 5-6: Percentage of environmental areas exposed to coastal inundation hazard

5.1.2 Tsunami

Exposure for tsunami is summarised in Figure 5-7 to Figure 5-13. Figure 5-7 shows population exposed to tsunami, Figure 5-8 shows the land area affected by tsunami in terms of percentage of land area affected within the mapping units. Figure 5-9 shows the impact of the tsunami on total area by land use classification. Figure 5-10 to Figure 5-13 provide further detail on road/rail infrastructure (Figure 5-10), water assets (Figure 5-11), social and cultural assets (Figure 5-12) and significant trees and conservation areas (Figure 5-13).

Tsunami inundation hazard exposure is significantly greater than coastal inundation. The most affected areas for the 3 m tsunami are E and F (greater than 80% land area affected) followed by areas D and J (greater than 30% land area affected). There is a significant increase in areas impacted with the 5 m tsunami and the majority of areas are impacted with the 10 m tsunami. However, in terms of population exposure areas D and E have moderate to high exposure for the 3 m tsunami. Exposure increases with the 5 m tsunami with areas D, I, K and O being highly exposed to very high. With the 10 m tsunami exposure is generally moderate to very high for most areas.

In terms of land use the main areas affected for the 3 m tsunami are recreational reserve land areas and industrial land, in particular the Port area (refer Figure 5-9), but the majority of land area types are affected with the 5 m and 10 m tsunami. A similar trend is observed for road, rail, water assets and trees and conservation areas (Figure 5-10, Figure 5-11 and Figure 5-13).

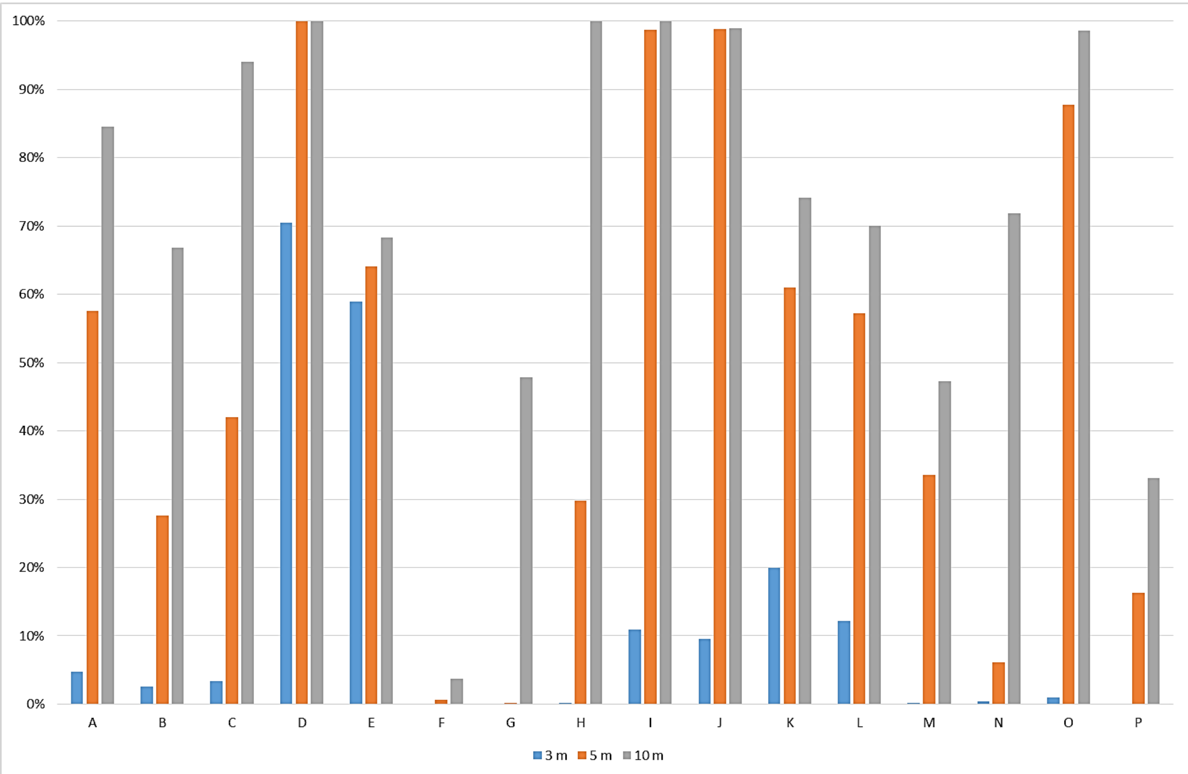

Figure 5-7: Population exposed to tsunami by mapping unit

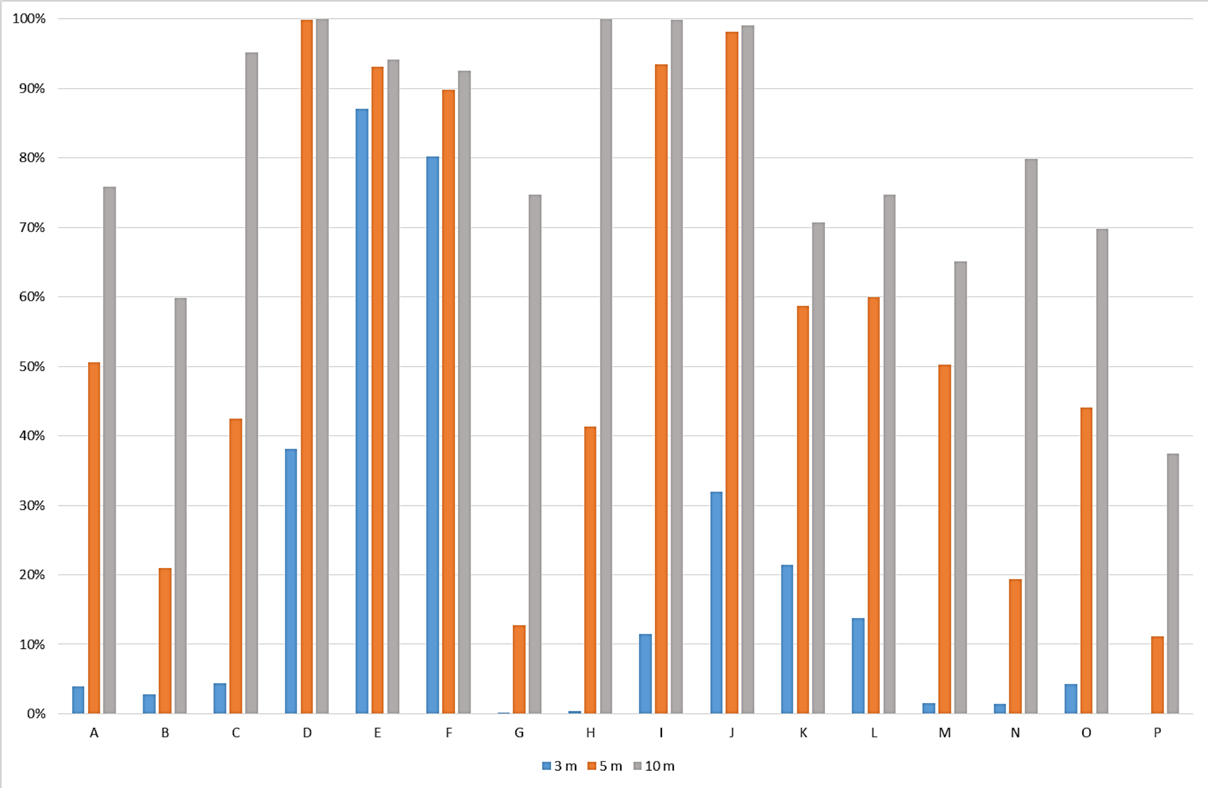

Figure 5-8: Percentage land area exposed to tsunami by mapping unit

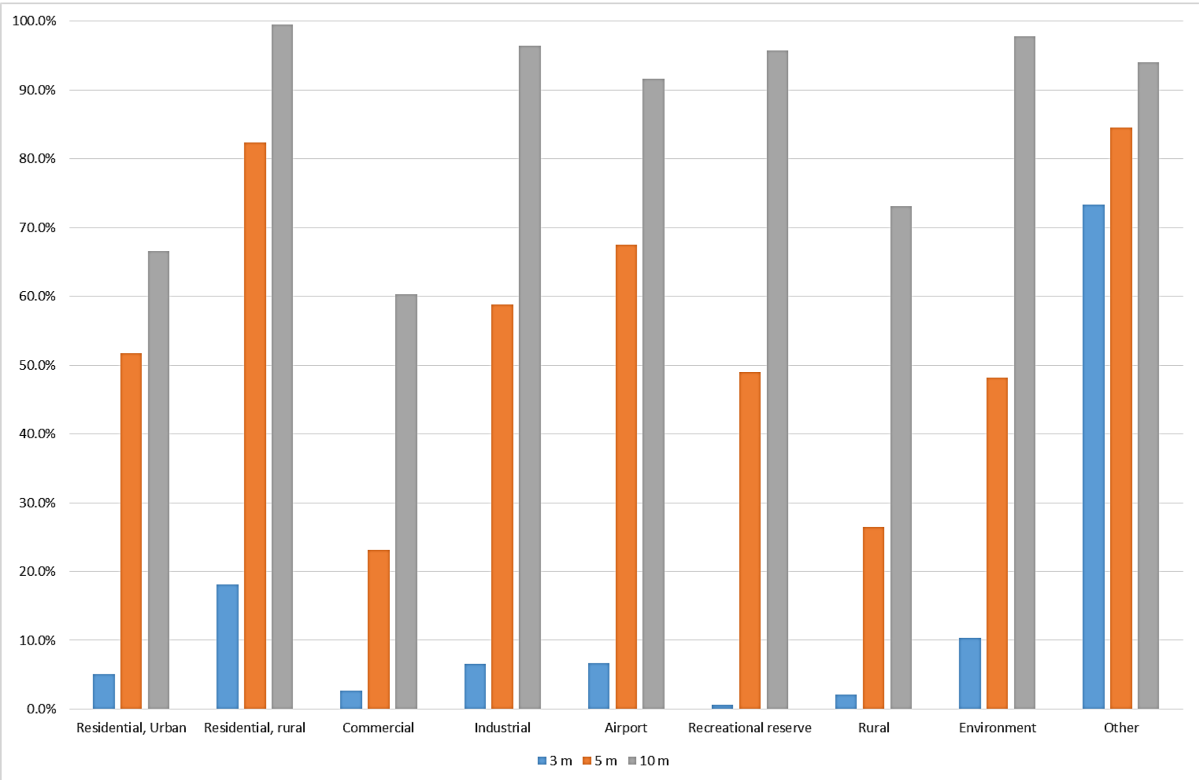

Figure 5-9: Percentage of land area exposed to tsunami hazard by land area classification

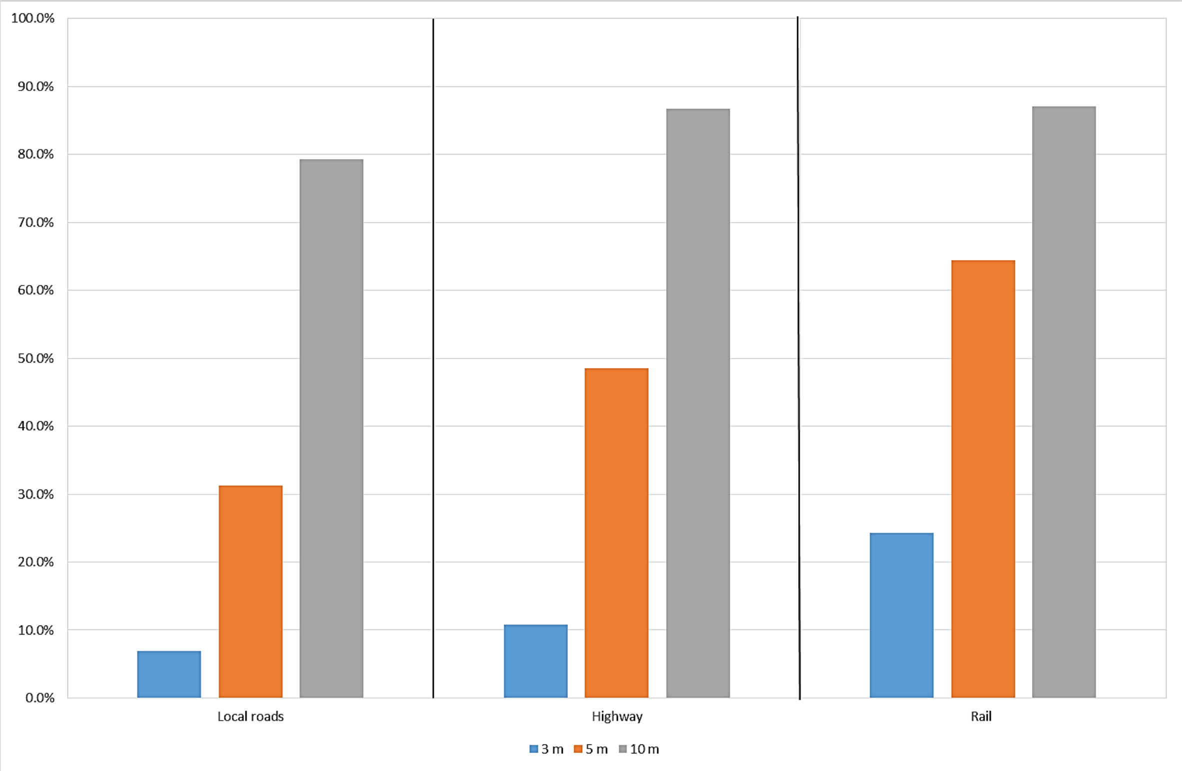

Figure 5-10: Percentage of road and rail infrastructure exposed to tsunami hazard

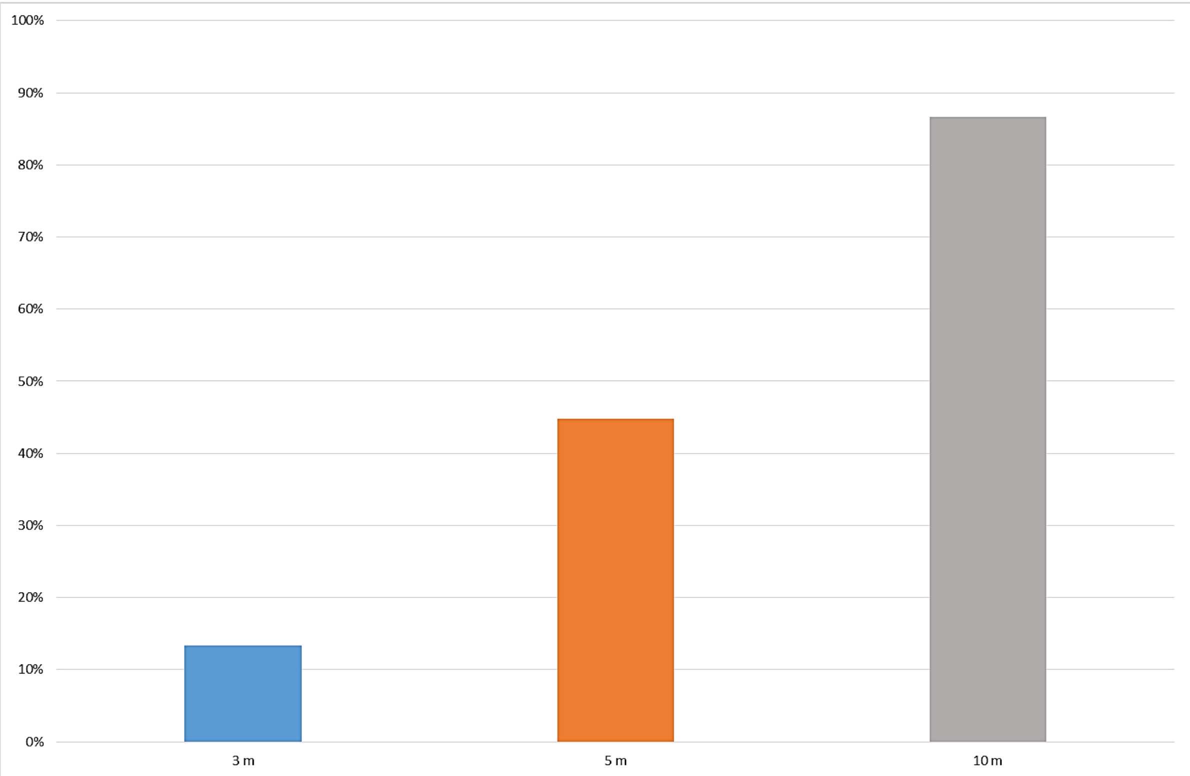

Figure 5-11: Percentage of water assets exposed to tsunami hazard

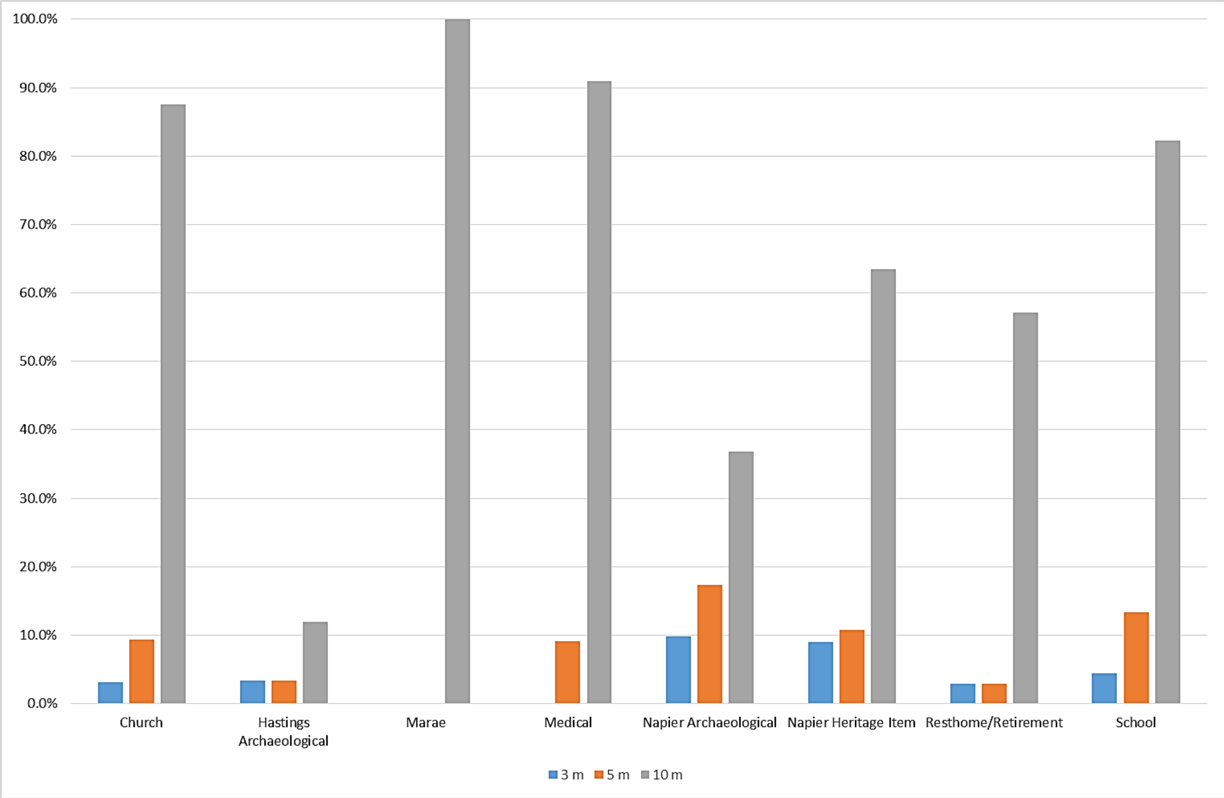

Figure 5-12: Percentage of social and cultural assets exposed to tsunami hazard

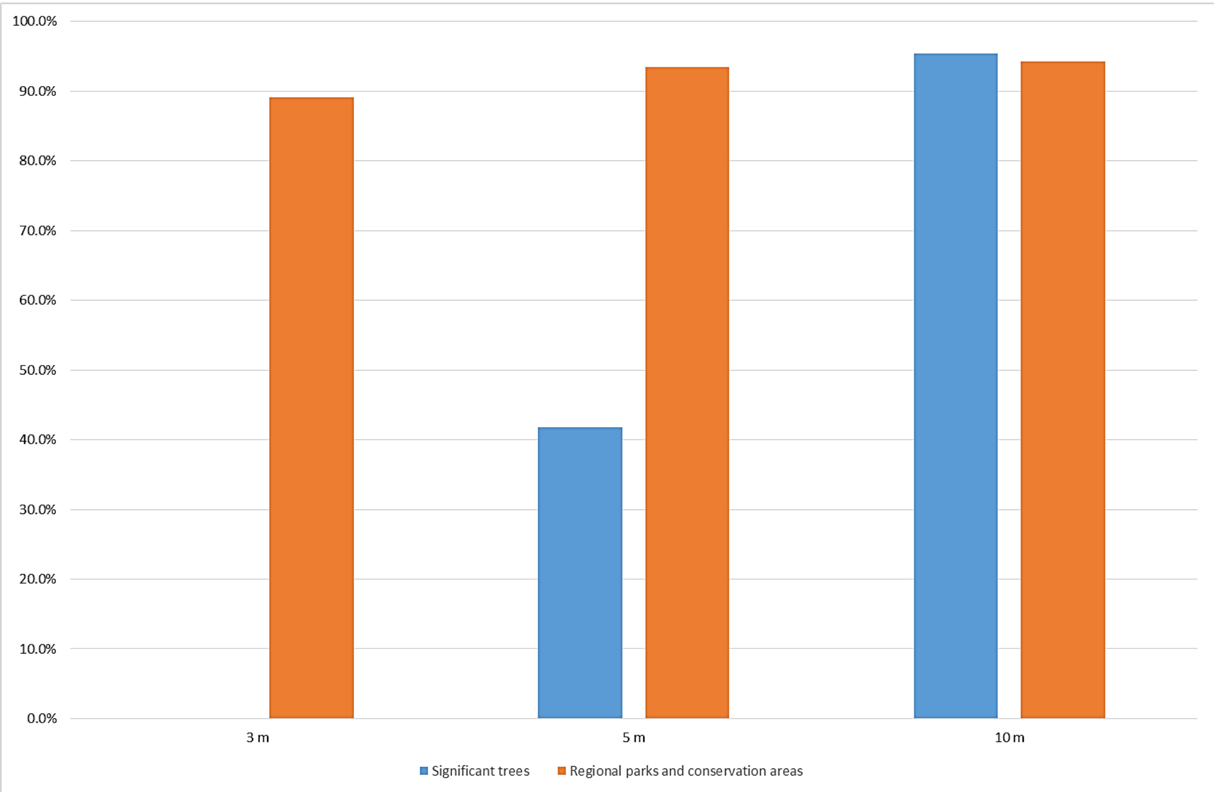

Figure 5-13: Percentage of significant trees and regional park/conservation areas exposed to tsunami hazard

5.2 Coastal erosion

For coastal erosion it has been assumed that erosion will affect the entire area seaward of the hazard line.

Exposure for erosion is summarised in Figure 5-14 to Figure 5-19. Figure 5-14 shows the land area affected by erosion in terms of percentage of land area affected within the mapping units. Figure 5-15 shows the impact of the tsunami on total area by land use classification. Further detail on road/rail infrastructure (Figure 5-16), water assets (Figure 5-17), social and cultural assets (Figure 5-18) and significant trees and conservation areas (Figure 5-19).

In the present day exposure is generally relatively low, with typically less than 5% apart from the southern Hawke Bay (areas J, K and L). With sea level rise exposure increases, particularly in areas A to D and J to L (refer Figure 5-14), the main land use area affected is recreational reserve and residential rural land (Figure 5-15). However, there is increased exposure to local roads and railway with increased sea level rise, but only at specific locations. However, it is recognised that effects at a particular location on these assets can affect a much longer stretch of the network.

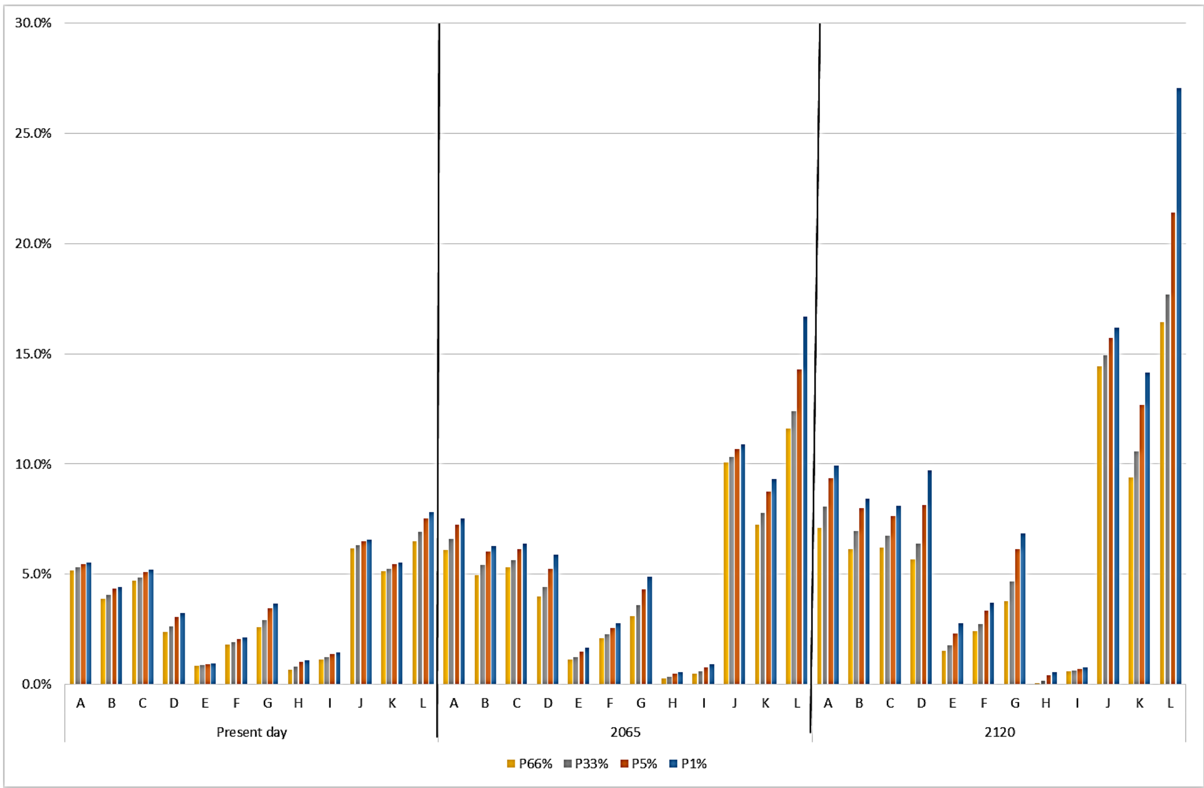

Figure 5-14: Percentage exposure to coastal erosion by mapping area

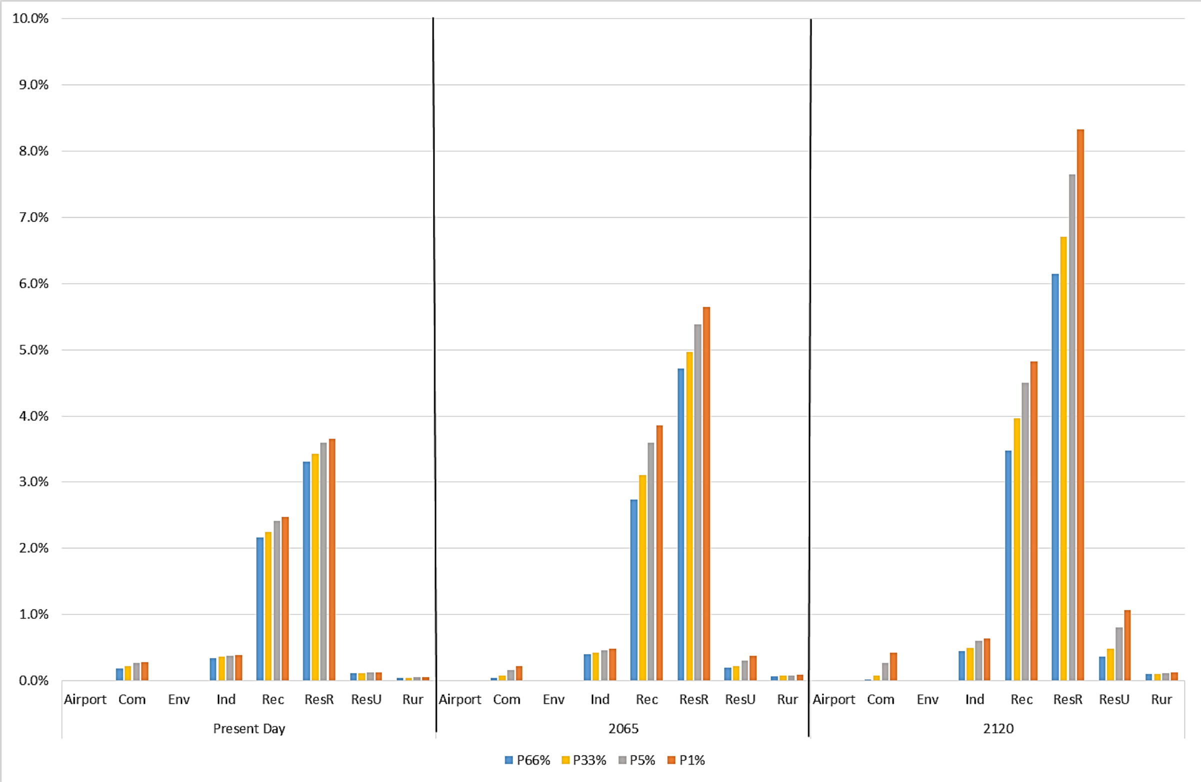

Figure 5-15: Percentage of land area exposed to coastal erosion by land area classification hazard

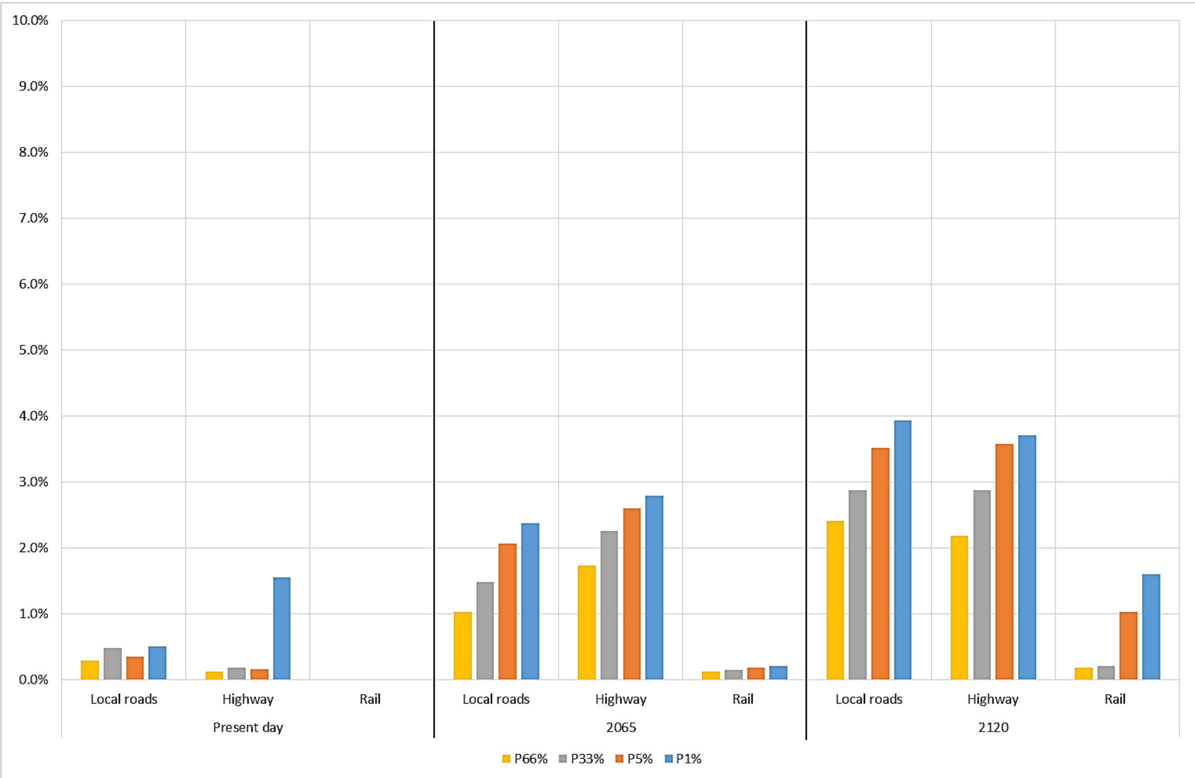

Figure 5-16: Percentage of road and rail assets exposed to coastal erosion hazard

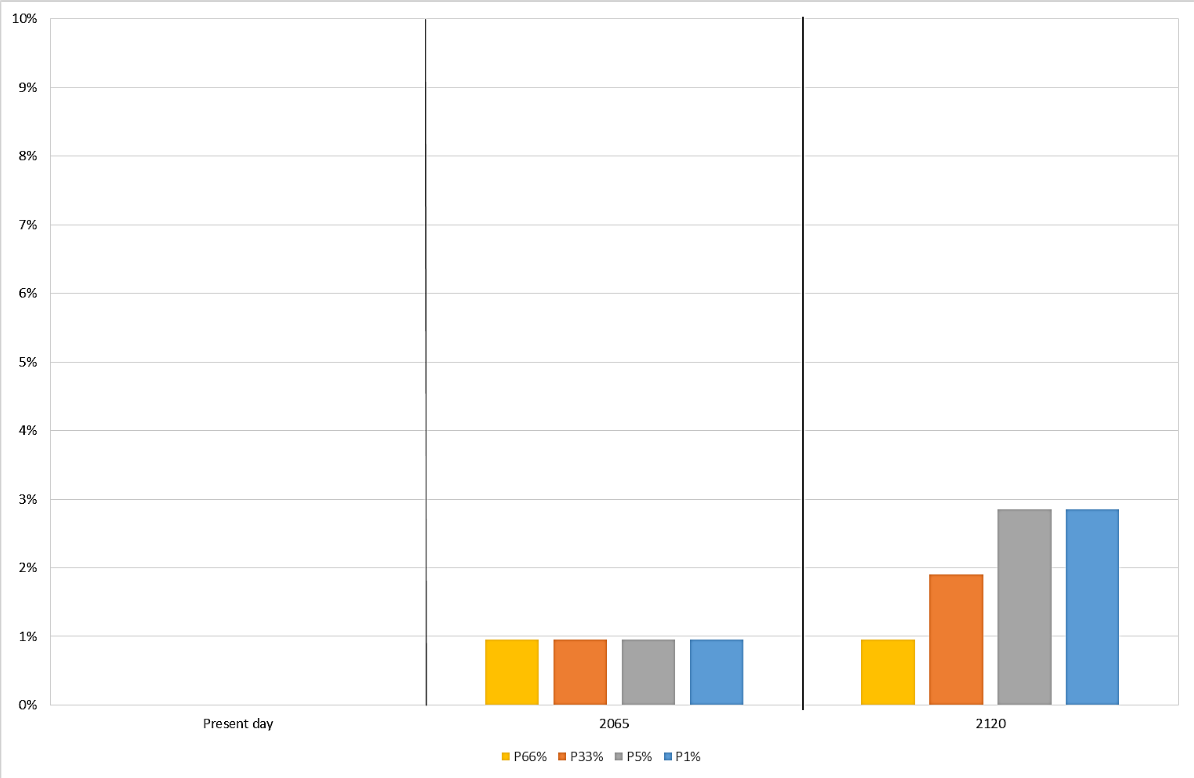

Figure 5-17 Percentage of water assets exposed to coastal erosion hazard

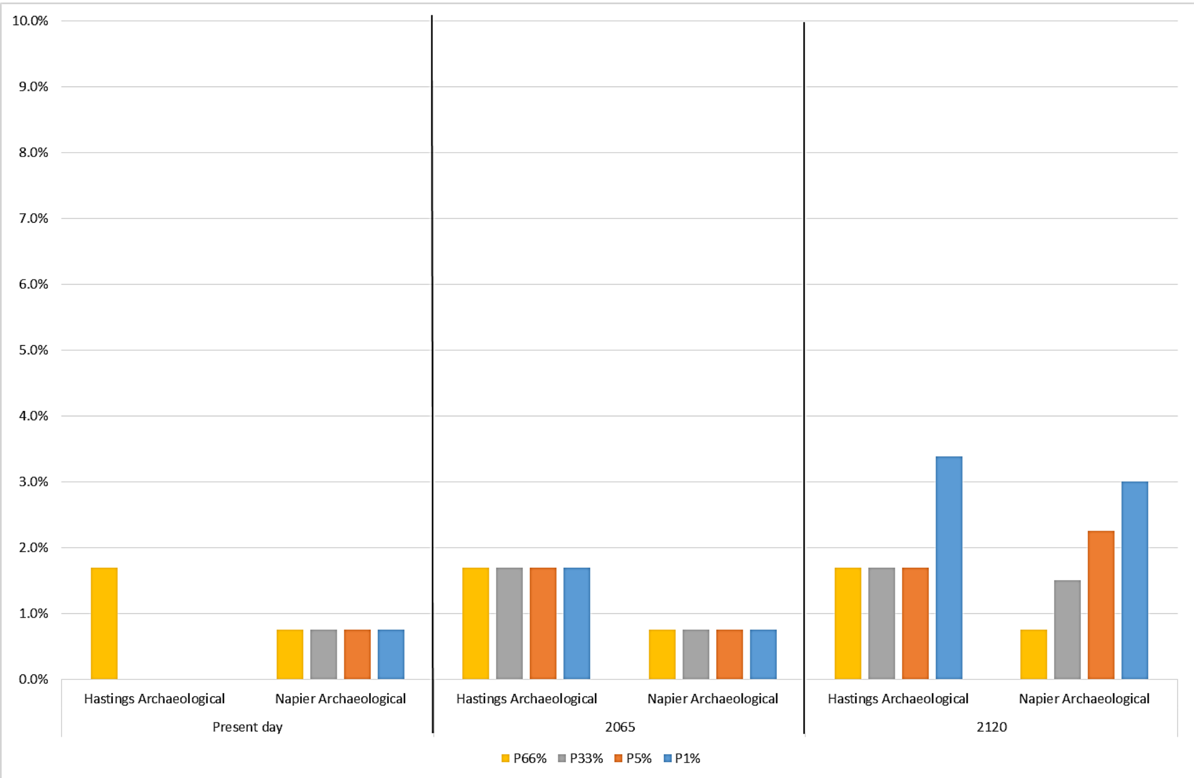

Figure 5-18: Percentage of social/cultural assets exposed to coastal erosion hazard

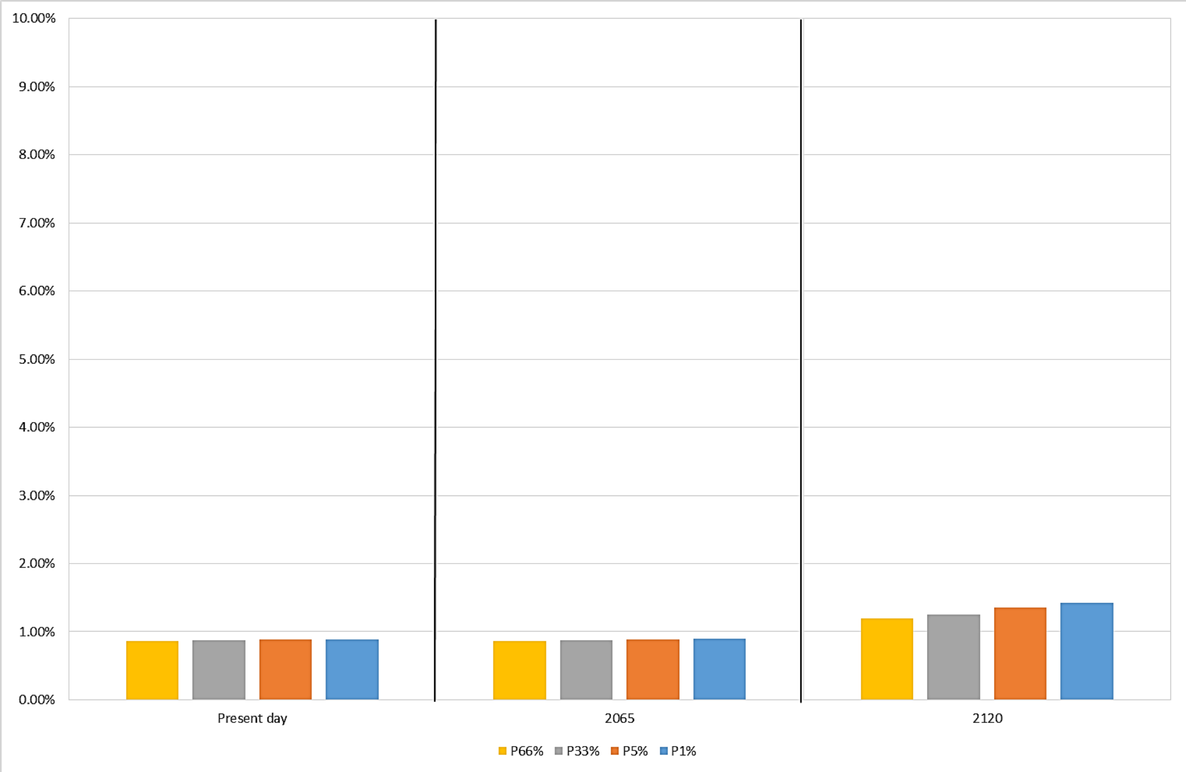

Figure 5-19: Percentage of environmental areas exposed to coastal erosion hazard

5.3 Summary

Exposure has been classified from low (1% to 30% exposure), moderate (30% to 70%), high (70% to 90%) and very high (> 90%). In terms of relative scale the tsunami hazard has a significantly greater exposure than erosion and coastal inundation. Coastal inundation has the next greatest exposure.

For coastal inundation exposure is generally low in the present day apart from the Ahuriri Lagoon area and the southern Hawke Bay where exposure is moderate. The exposure in most areas increases in 2065 and there are a greater number of moderate to high exposures at 2120. In terms of land use type, conservation land has high exposure, recreational land exposure is moderate and the remaining land use types and other elements have low exposure.

For tsunami hazard, exposure is generally low for a 3 m tsunami for most of the areas apart from area D, E and F where exposure is moderate to high. All mapping unit areas exposure is high to very high for a 10 meter tsunami height apart from Area B and P where exposure is moderate. This trend is observed for all elements at risk.

For coastal erosion exposure is generally low as it affects only the coastal margin. However, the exposure increases progressively with sea level rise, particularly at the northern and southern ends of the study area. The main land areas affected are recreation and rural residential land, although there is an increasing exposure to all elements at risk with increased sea level rise.

6 Vulnerability

Vulnerability is the assessment of the physical impact of a particular hazard on the built environment and population to provide a quantification of loss. For the vulnerability analysis for this study the physical parameters of the hazard (water depth and loss of cadastral areas) have been related to the element at risks.

6.1 Loss modelling approach

An assessment of loss has been made for each hazard for human, economic, social/cultural and environmental/ecological elements at risk. Different approaches have been applied for each of these elements and the approaches are described below.

6.1.1 Human injury and death

Tsunami related injury and deaths are anticipated to be significantly higher than might occur with sea inundation, as a near field tsunami can reach landfall in less than 1 hr. However, estimating the potential human injury and death toll for tsunami is complex and is not a precise science due to the relative rarity of significant tsunami events. For the purposes of this study, the impact on human injury and death as a result of tsunami has been based on Horspool et al. (2015) models of loss:

Number of deaths = number of people exposed x 0.04 x water depth (m)

Number of injured people = number of survivors x 0.04 x water depth (m).

It is noted that this approach is based on limited data and does not include casualty data from the recent tsunami in Japan or the Indian Ocean (Horspool et al., 2015). Fatality rates from the 2011 earthquake in Japan give fatalities ranging from around 1% to 9.3% for the towns and cities along the coastal edge and the ratio of injured to dead and missing is around 1.4 (i.e. 27,074 injured and 19,334 dead or missing). http://earthquake-report.com/2012/03/10/japan-366-days-after-the-quake-19000-lives-lost-1-2-million-buildings-damaged-574-billion/.

No impact on human injury or death has been applied to areas affected by coastal inundation or erosion. Even with high coastal inundation exposure, mortality rate is typically low due to advanced warning of weather systems, community preparedness and other interventions (Ishiguro and Yano, 2015). While sea level rise will increase inundation exposure it is unlikely to be a rapid change that increases risk of injury and death. For coastal erosion no loss of human life is expected as the erosion process is also expected to be slow and progressive, rather than rapid and it is assumed that evacuation and avoidance of this hazard will be possible.

6.1.2 Economic loss

6.1.2.1 Coastal inundation and tsunami

Economic losses for coastal inundation and tsunami have been calculated by multiplying the value of the element at risk by a fragility function. In this instance the fragility function provides an estimate of damage to a specific element at risk with increasing water depth. Fragility functions for each elements are set out in Section 6.2.

Economic values for specific land use areas have been obtained from Council's data base. Inundation and tsunami loss calculations are based on 1.5 x improvement value as per council valuation data on the basis that the land itself is not permanently damaged. The 1.5 factor provides an allowance of damage to personal assets within the building. For roads and rail, inundation and tsunami loss calculations are based on replacement values as outlined in Table 3 3.

6.1.2.2 Coastal erosion

It has been assumed that erosion will affect the entire area identified and all land value and improvement value within the coastal hazard area is lost. For property where there are values attributed in Council's rating data base, this has been calculated as the proportion of capital value (i.e. land and improvements) subject to erosion (i.e. the exposed area divided by the total area) plus the replacement water network cost per property as set out in Table 3-2. No additional factor was applied to take into account personal assets as it has been assumed there would be sufficient time to remove most assets. For road and rail the loss calculation also includes estimated land value. The economic impact results also include water assets, however it is noted that valuation data is only available for Napier City council water assets.

6.1.3 Elements without cost values attributed

For elements where the cost, or value, is not prescribed (i.e. social or environmental elements), a simple weight assignment procedure has been applied:

No exposure:	<1%
Low:	1% to 30%
Moderate:	30% to 70%
High:	70% to 90%
Very high	> 90%

In that way, the magnitude of damage can be estimated either in monetary and non-monetary units. As stated by Meyer and Messner (2006) "every element at risk is more or less exposed to events and more or less susceptible to them, exposure and susceptibility indicators are related to element-at-risk indicators and contribute significantly to the analysis of vulnerability".

6.2 Fragility functions for inundation and tsunami

Fragility function have been applied to calculate potential damage costs to a given structure and its contents for a range of different inundation depths. Synthetic vulnerability curves also reflect the 'potential' damage, where issues that can affect losses – such as flood warning, flood history, precautionary measures – are not incorporated. To account for this deficiency, additional multipliers are often used to adjust potential to actual loss (Matthew et al., 2011; Thieken et al., 2005).

We have considered a range of fragility functions including FEMA HAZUS-MH model of USA (FEMA, 2015), HAZUS Tsunami Benchmarking for Japan (Ronald et al, 2013), RiskScape model for New Zealand (GNS-NIWA, 2015), Australian (Mason and Phillips, 2011); Belgium CONHAZ model (Green et al., 2011) and Shanghai flood damage model (Ke et al., 2012) and selected a preferred damage curve based on our judgement of the most appropriate configuration. The following section sets out our approach for each of the elements at risk, with plots of the fragility functions considered and our selected function for each element identified as a solid line.

6.2.1 Residential Urban and Rural (Res U & Res R)

Figure 6-1 shows a range of fragility functions for residential buildings from RiskScape along with other international standard curves from the Hazus, Australia, Belgium and Shanghai models. The Australian fragility function is the most conservative (highest damage value), and the RiskScape and Hazus curves have a similar shape compared to the Shanghai and Belgium functions, which show significantly lower rates of damage. It is assumed that this is due to the different typical construction materials for buildings in these areas. The GNS (2015) fragility function from Horspool et al., (2015) models similar to the Australian model and estimates higher from 4 meters above depth. The Australian fragility function (blue solid line) represents large-scale floods and therefore has been selected to best represent damage effects for depth up to 4 meters resulting from tsunami and sea inundation.

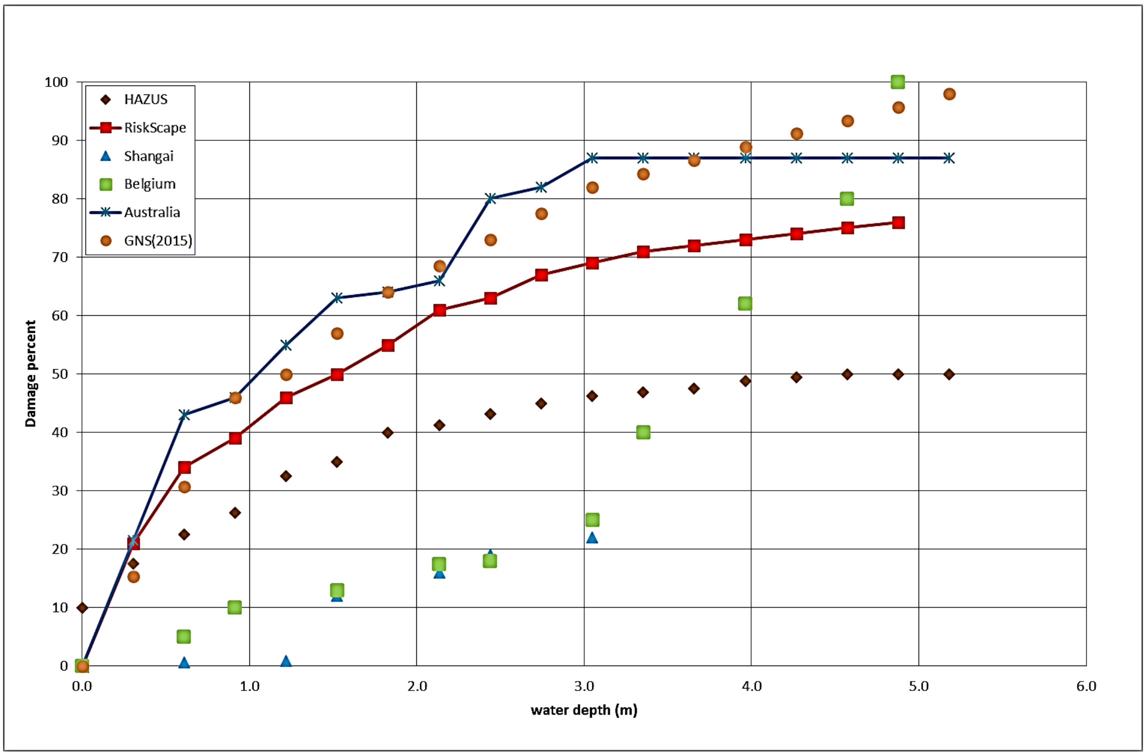

Figure 6-1: Residential damage curves for urban and rural. The blue line has been selected to represent fragility for tsunami hazard and the red line the fragility for sea inundation hazard

These functions have been assumed to represent all residential housing stock, irrespective of building material or number of floors as the fragility functions for these building types are reasonably similar as shown in Figure 6-2 below.

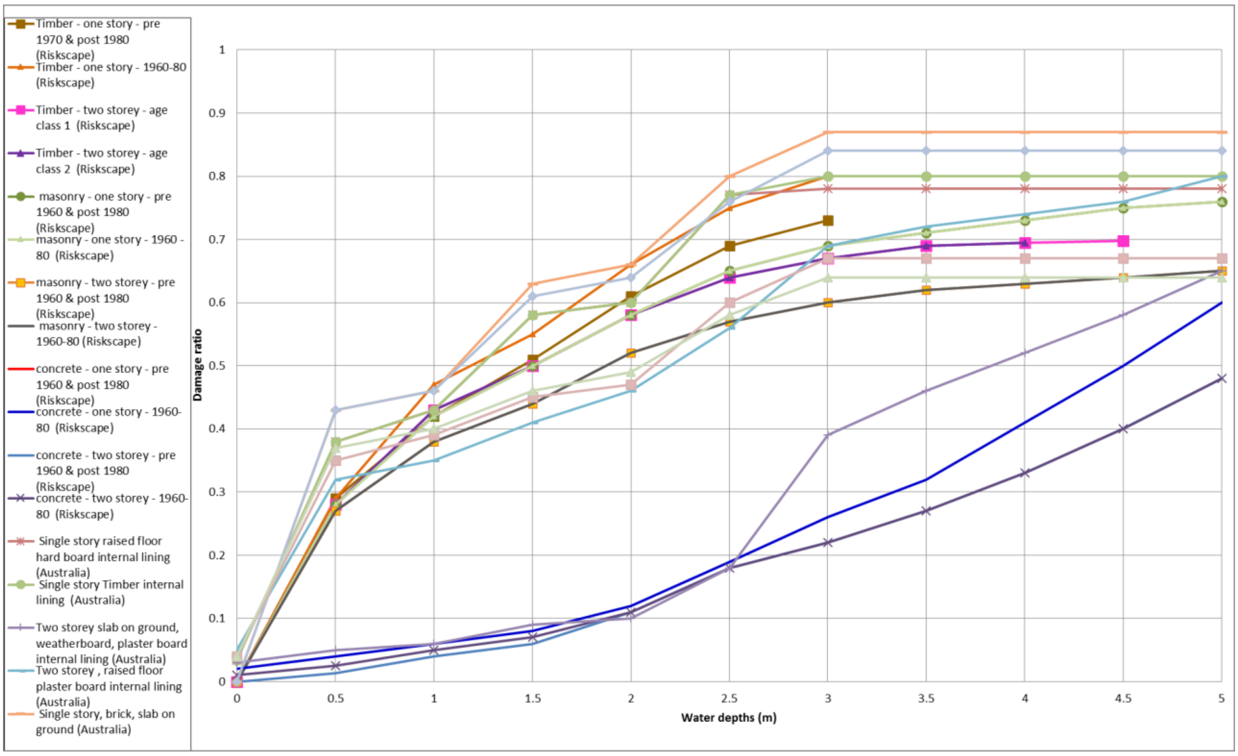

Figure 6-2: Range of fragility functions for different building materials and number of floors

6.2.2 Industrial damage (Ind)

The range of fragility functions for industrial damage is shown in Figure 6-3. The plot shows a relatively wide range of damage for increased flood depth. Comparing the industrial case, both the Hazus and Australian function gives a similar curve to residential development, with a reasonably rapid increase in damage, which then levels off. It is also similar to the GNS (2015) fragility function. We note the RiskScape function is different, with much less damage resulting from inundation, but that this function is based on limited literature and information about the behaviour of these types of buildings. Due to the limited data in RiskScape and the consistency with Hazus, GNS (2015) and the Australian function we have used the Australian fragility function to represent the damage to industrial zoned properties for both sea inundation and tsunami.

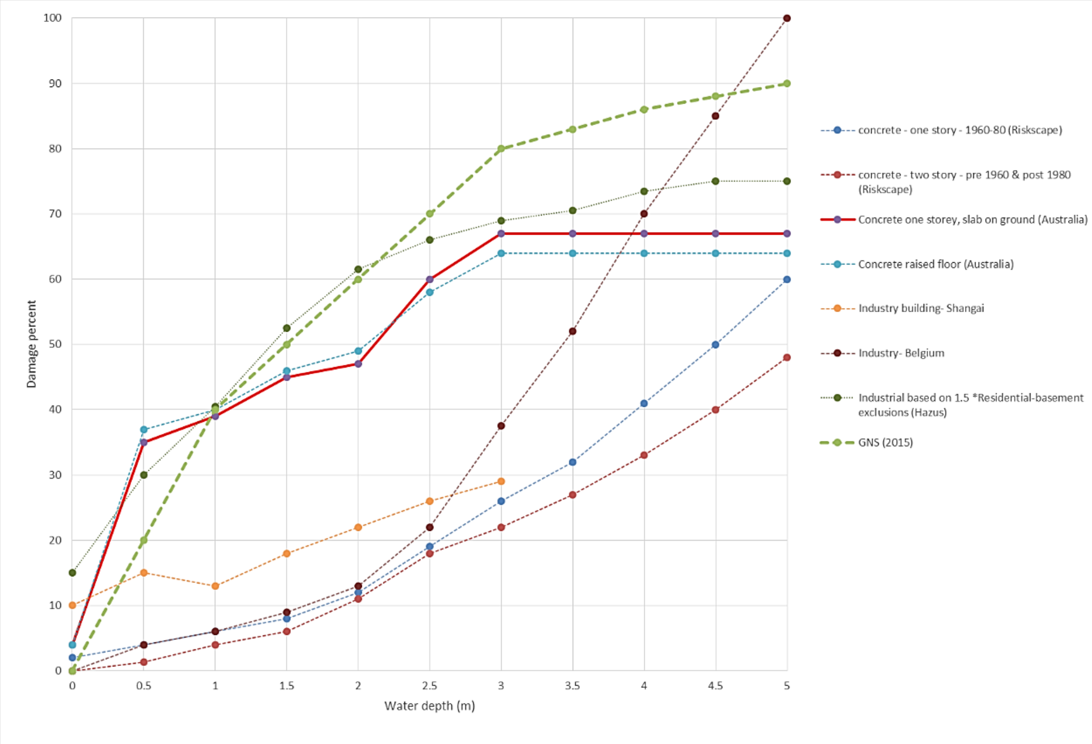

Figure 6-3: Industrial damage curves for both inundation and tsunami

6.2.3 Commercial damage (Com)

The commercial category includes office-type buildings, retail shops and public facilities. Little information exists on potential flood depth-damage relationships for different types of retail companies and public facilities in New Zealand and it is likely to be highly variable (NIWA, 2010).

Figure 6-4 shows the available fragility functions for commercial property damage. The Australian function was based on the damage of buildings in Queensland and Victoria following the 2010–11 Eastern Australia flooding where insured losses reached AUD 2.5 billion. In RiskScape, the basic assumptions were similar to the residential content fragility curves, with a difference only in floor-to-ceiling height (NIWA, 2010) as commercial buildings typically have a higher average floor-to-ceiling height (around 3 m). The Australian single story slab on ground function was selected to provide the inundation damage function both for sea inundation and tsunami.

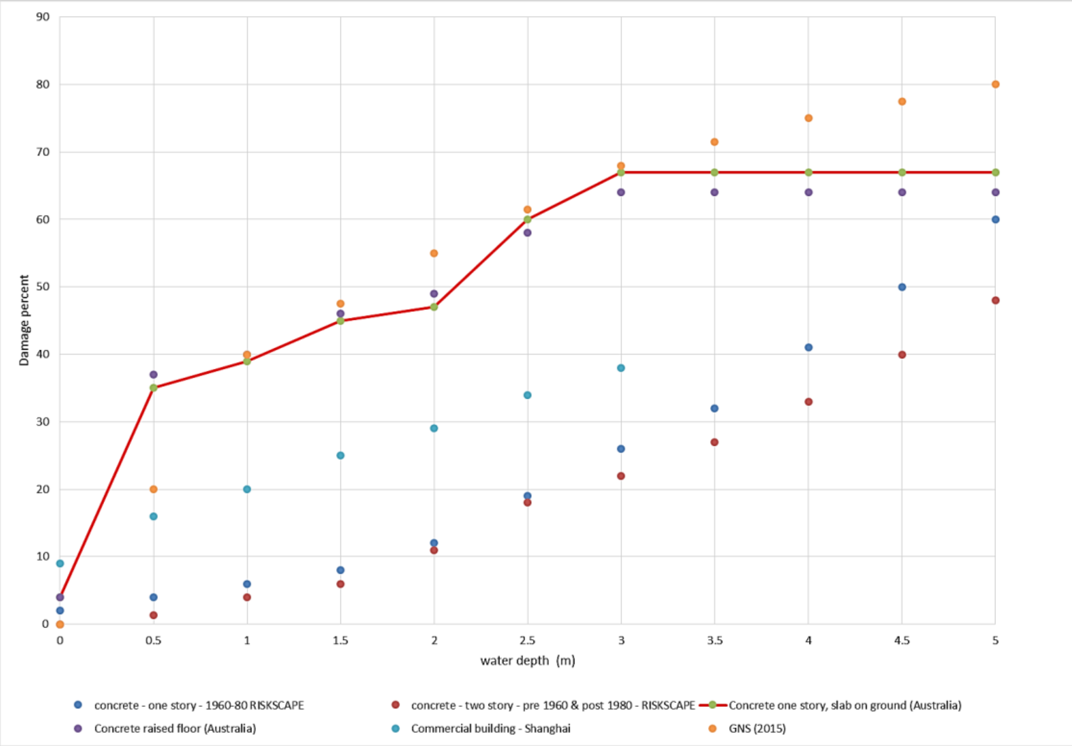

Figure 6-4: Commercial damage curves

6.2.4 Rural land

There are only a limited number of damage functions related to agriculture (Hazus TM). In the coastal area of Hawke Bay key land uses are expected to be grape production/fruit orchards and grazing. The damage to crops is not generally dependent on the depth of flooding, but when the flood occurs and the duration of the flooding. However, with coastal inundation or tsunami, the inundation of salt water is expected to have some impact and the function set out in Figure 6-5 has been applied to these areas.

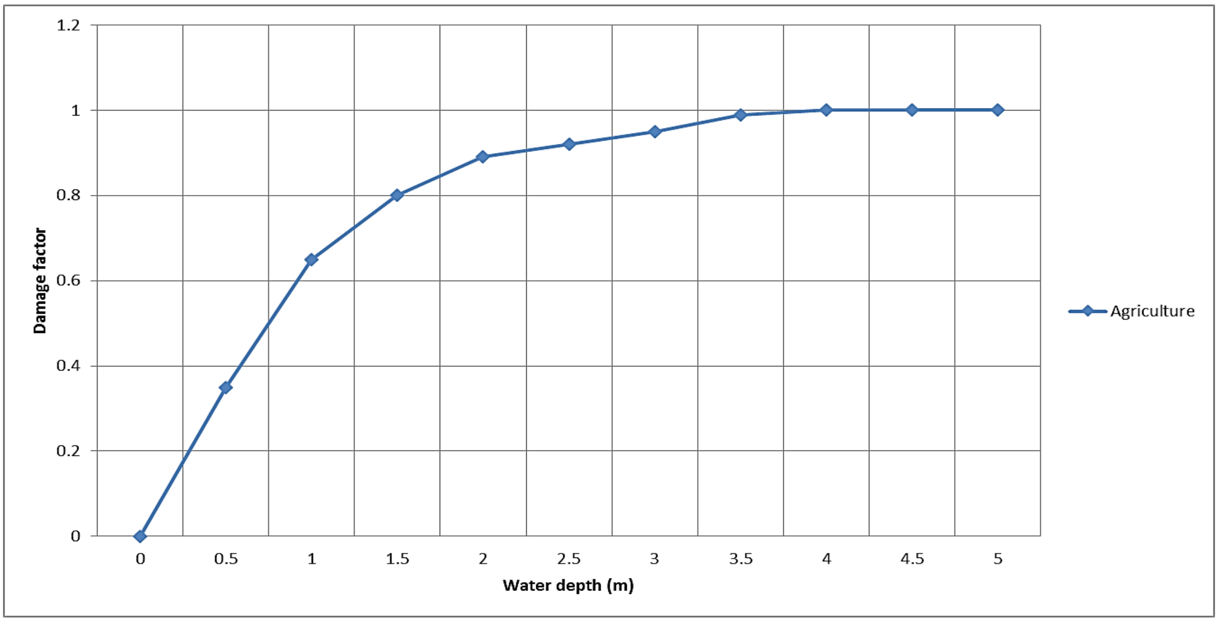

Figure 6-5: Relative depth damage function for agriculture from Belgium

6.2.5 Road damage (Road)

There is less available information on road damage fragility functions. Figure 6-6 shows information from Hazus, Japan and Belgium. All three models represent a linear relationship. The damage function from Belgium was selected as this provided an upper bound of damage and was similar for greater levels of inundation to the fragility function for Hazus.

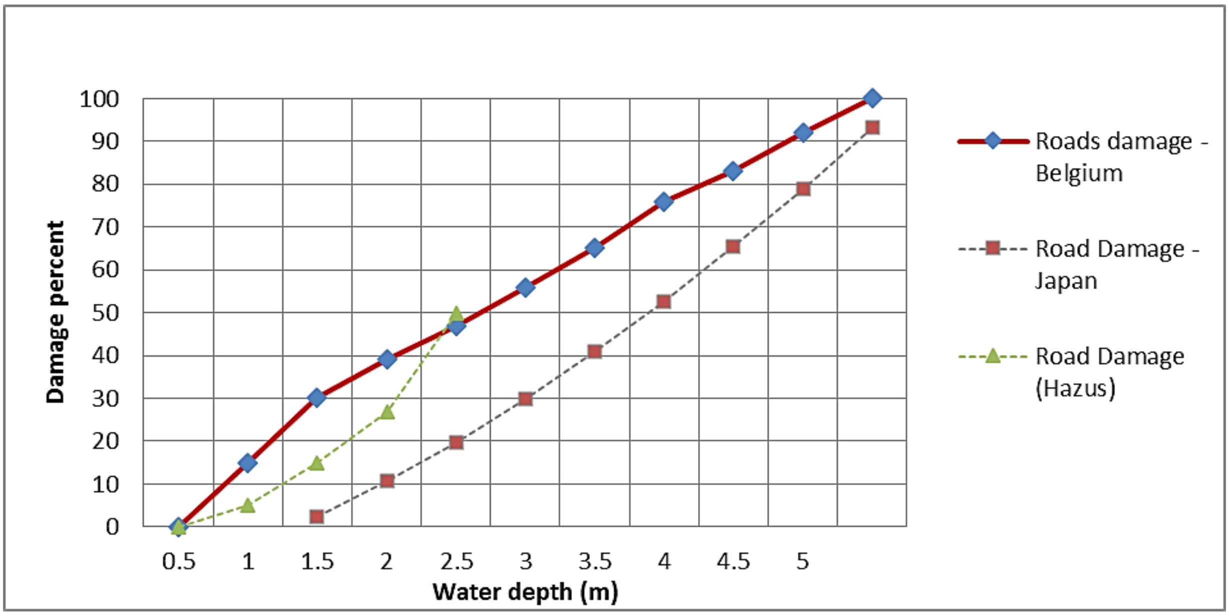

Figure 6-6: Road damage curves

6.2.6 Rail damage (Rail)

The rail damage curve (Figure 6-7) is based on the study "Estimating flood damage to railway infrastructure – the case study of the March River flood in 2006 at the Austrian Northern Railway" (Kellermann, et al., 2015). A statistical model was used based on damage to the Northern Railway in Lower Austria caused by the March river flood in 2006. A direct relationship has been established based on empirical data and photo-documented damage.

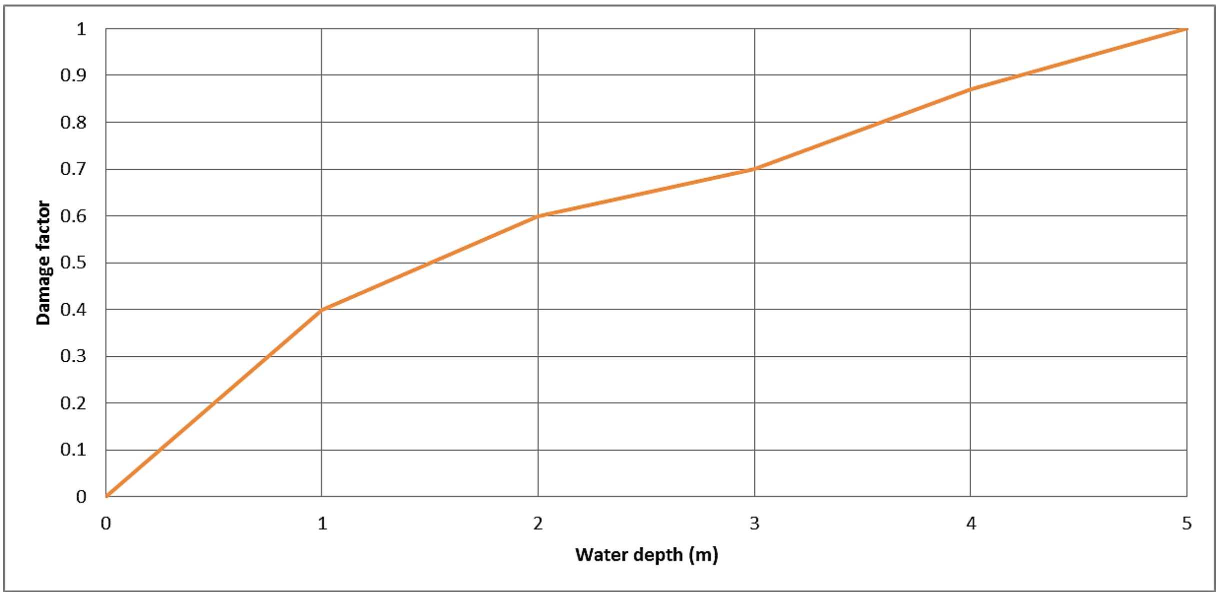

Figure 6-7: Damage curve for rail infrastructure based on Austrian flood damage estimates

6.2.7 Airport damage (AP)

Damage to the airport was taken to be a combination of commercial building damage (Figure 6-4) and road damage (Figure 6-6) for the runway area.

6.2.8 Port Damage

Port damage relating to inundation and tsunami was assessed using the industrial fragility function. No land loss or damage due to erosion was taken into account due to the port structures.

6.2.9 Electrical power and communication systems

Electric power classifications, functionality thresholds and damage functions have been taken from the Hazus model. For the high voltage substation, we considered the control room damage as starting at 0 m and being maximized at a 2 m depth. There was also additional damage to cabling and incidental damage to transformers and switchgear.

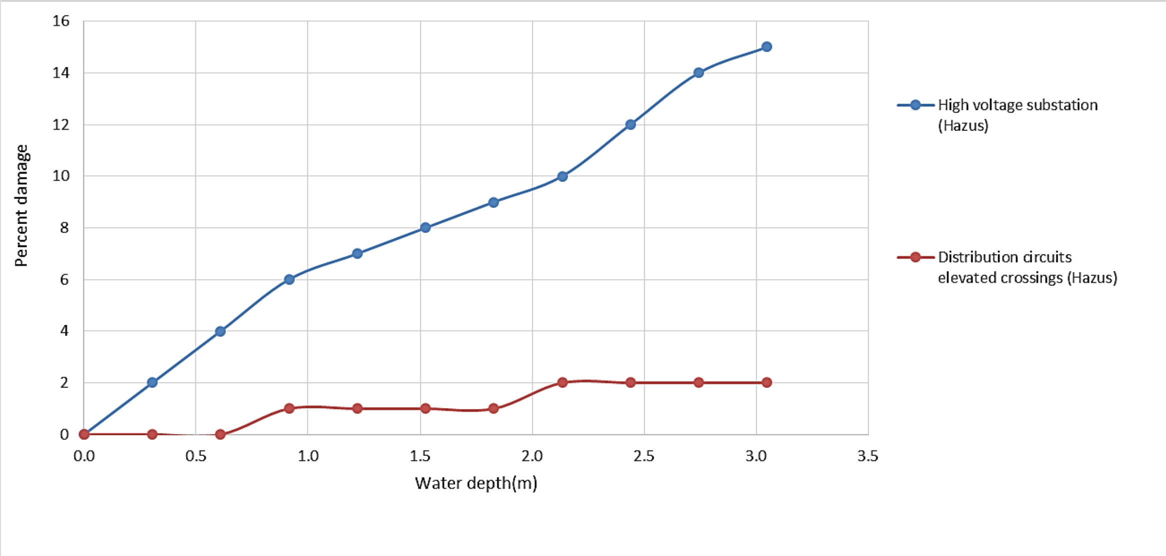

Figure 6-8: Substation and distribution network damage functions

6.2.10 Wastewater utilities (Util)

There is very little fragility data on water transportation networks available in the international literature. Figure 6-9 shows damage curves from Hazus and RiskScape for small treatment plants. While Hazus provides a comprehensive set of flood fragility functions for various utility elements including the water network, the applicability of these curves to New Zealand's water transportation system is not certain. The RiskScape fragility functions have been developed in collaboration with engineers from Christchurch City Council. This provided estimates of possible damage dependent on water depth within the plant. We have therefore selected the RiskScape fragility function.

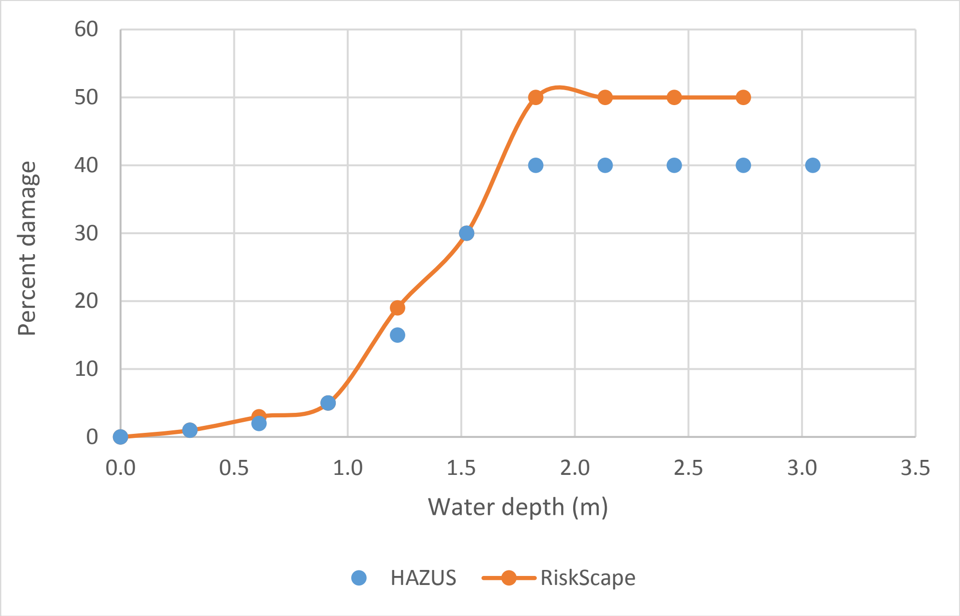

Figure 6-9: Damage curves for small wastewater treatment plants

6.2.11 Other damage risks

There are risks for direct losses that have not been considered in this study. These include vehicle losses and goods that may be stored in warehouses and port facilities as well as other forms of private loss. There are also indirect losses that occur as a result of the event, such as transport disruption, business loss or clean-up costs. All of these factors increase the actual cost of recovering from the hazard for the community.

6.2.12 Early warning systems and a means to reduce risk

While not considered in this current stage, it is well known that advance warning of hazards can assist in reducing risk due to the ability to evacuate people potentially at risk and enabling contents to be moved to safer areas. Fragility functions are recommended in RiskScape to calculate varying degrees of loss for flood damage comparing different warning times (refer Figure 6-10). Due to the lack of data average damage reduction values from the above sources are used for residential, commercial and industrial buildings. For commercial buildings, a 1%, 5% and 10% content damage reduction was assumed for the three warning lead time categories. Industrial buildings have primarily heavy machinery and less movable objects, so the damage reduction is assumed to be lower.

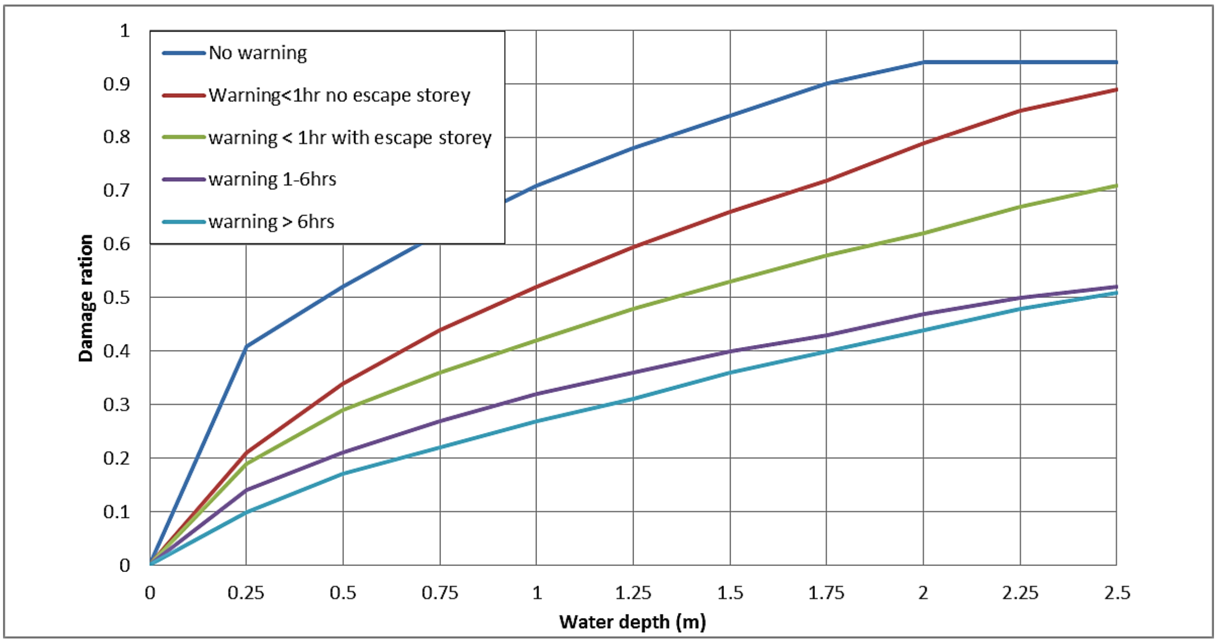

Figure 6-10: Damage curve for early warning system

7 Risk assessment results

This section presents results in terms of total losses for each hazard as it applies to the four main elements at risk (human, economic, social/cultural and environmental/ecological).

7.1 Human loss

7.1.1 Human loss for tsunami

Human loss, in terms of fatalities and injuries resulting from the three tsunamis modelled, are calculated based on the methodology summarized in Section 6.1. Figure 7-1 presents total human fatalities and Figure 7-2 for human injuries. Total human impact (fatalities and injuries) by mapping unit under tsunami hazard are shown in Figure 7-3 using the following classification:

Very low: < 10

Low: 10 to 50

Moderate: 50 to 100

Large: 100 to 500

Very large: > 500.

The results show that the urban area of Napier (mapping area E, N and H) has the highest risk of human loss in terms of injury and fatalities due to the high concentration of population in this area.

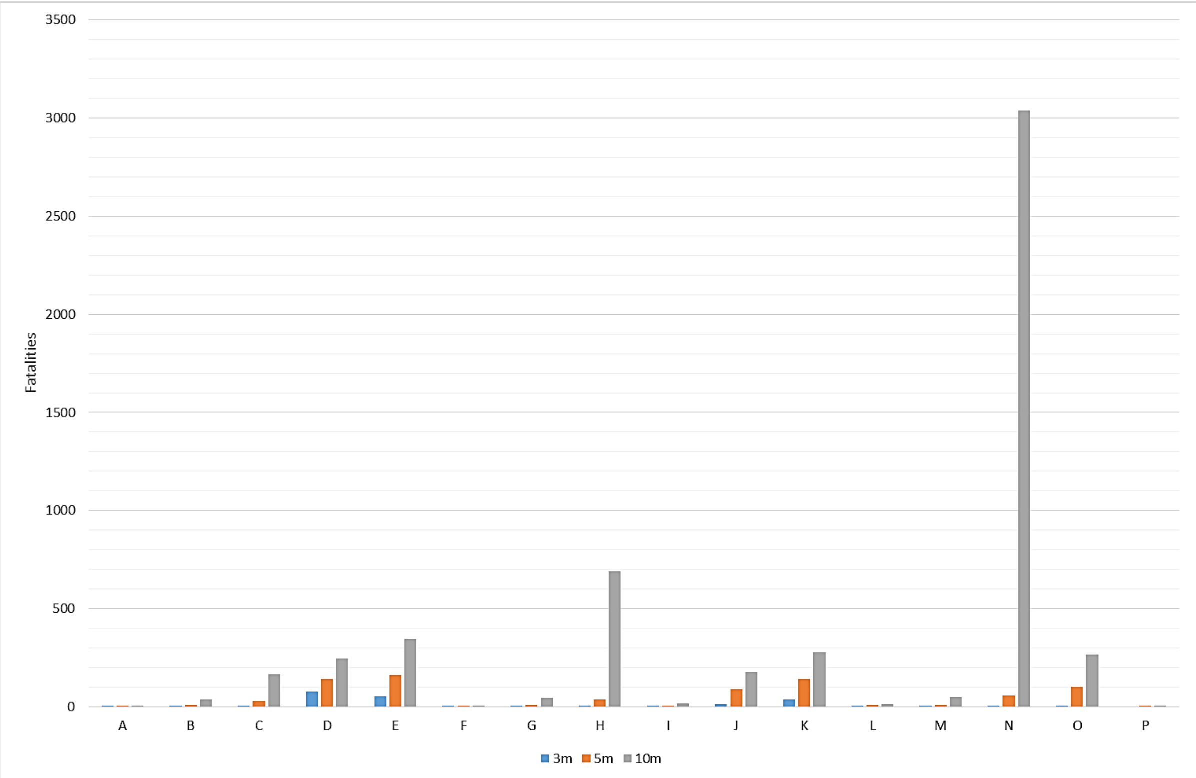

Figure 7-1: Total human fatalities by mapping unit for the tsunami hazard

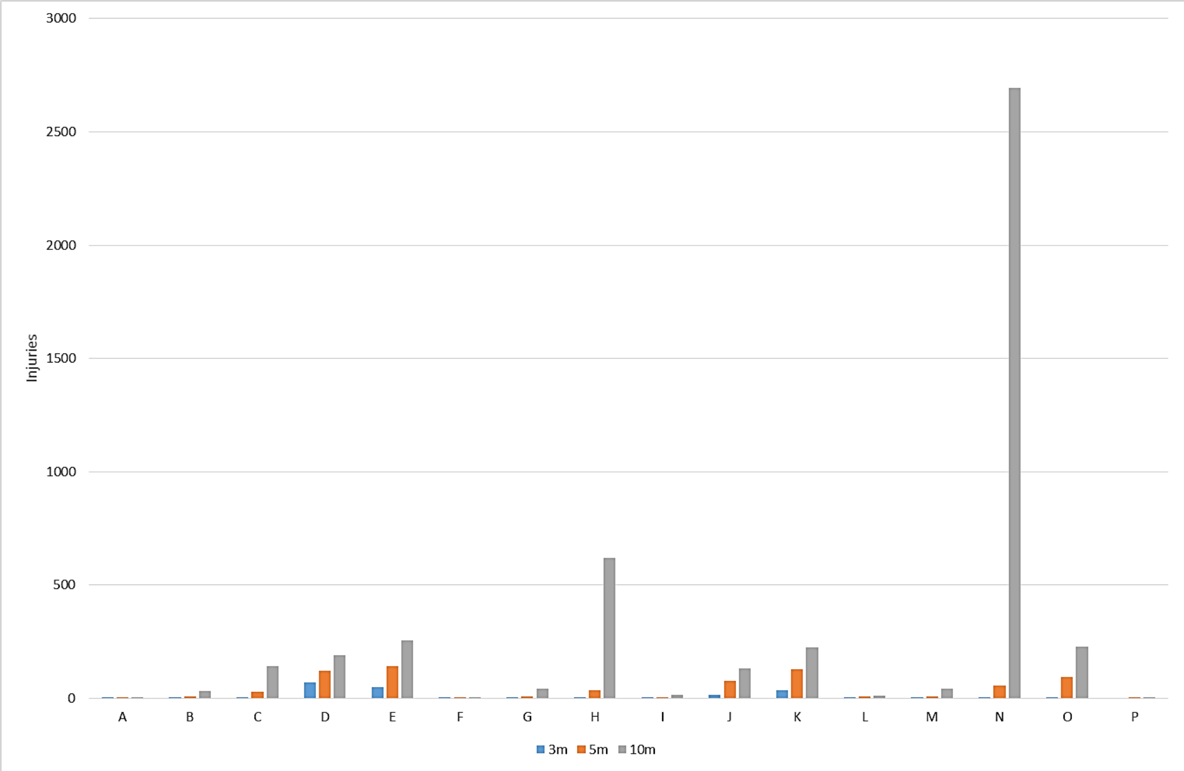

Figure 7-2: Total human injuries by mapping unit for the tsunami hazard

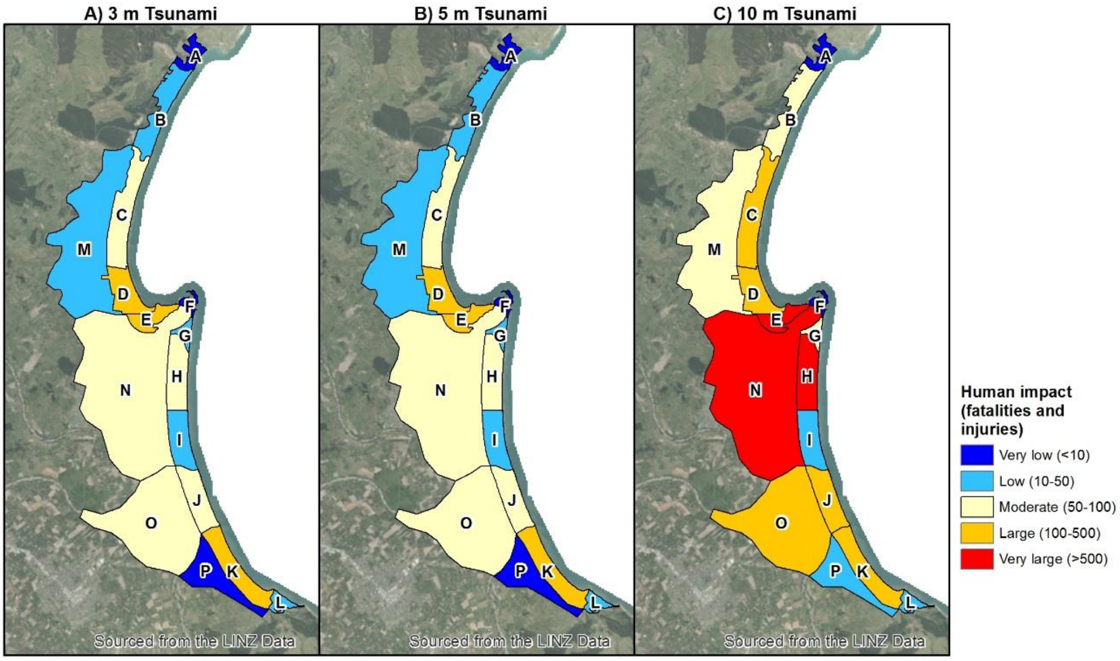

Figure 7-3: Combined human impact (fatalities and injuries) by mapping unit for the tsunami hazard

Potential fatalities of around 4,100 and injuries of around 3,600 are estimated for the 10 m tsunami in the Napier City area (area E, G, H and N). The fatalities represent around 8% of the total population. This is within the range of observed fatalities from the 2011 earthquake in Japan, but towards the upper bound (refer Section 6.1.1). The total fatalities for the region is around 5,400 and 4,600 (fatalities/injuries). The fatalities represent around 7% of the population.

We note Horspool et al. (2015) study for the overall Napier calculated fatalities up to 9,000 population for a 2500 return period and injuries up to 6,000 population for a 2500 return period. These estimates are significantly higher than in our assessment. The fatalities represent around 12% of the population which is higher than that observed in Japan. It is likely that these high numbers are due to a more simplistic schematization of the tsunami extent by Horspool.

The individual risk in terms of probability per year can be evaluated by multiplying fatalities and injuries by the estimated return period of the tsunami event. The results of this assessment per mapping unit are shown in Table 7-1. These individual risks can be compared to other causes of fatality risk shown in Table 7-1 that are based on international literature (not NZ specific). Comparing tsunami with other risks it can be seen that even though the tsunami events have a low probability of occurrence, due to their potential consequence the individual fatality risk is higher than a range of other community risks.

Table 7-1 Individual risk for typical causes (Source: University of Twente, the Netherlands, 2014)

Cause	1 chance in n/year	Cause	1 chance in n/year
All causes (illness)	84	Rock climbing	125
Road accidents	10,000	Canoeing	500
Accidents at home	10,753	Hang-gliding	667
Fire	66,667	Motor cycling	4,167
Drowning	166,667	Accidents at offices	222,222
0.5% AEP tsunami	1	0.025%AEP tsunami	0.75

7.1.2 Human losses for inundation and erosion

As no impact on human injury or death has been applied to areas affected by coastal inundation or erosion the risk of human injury or fatality has been classed as very low in all areas.

7.2 Economic loss

Tsunami, coastal inundation and erosion risk, assessed by calculating total economic losses are presented in this section.

7.2.1 Economic loss for tsunami

The total economic losses calculated for tsunami hazard of each mapping area shown in Figure 7-4. The losses are classified into six classes shown in Table 7-2 Classification of economic impact for tsunami hazard to assess the tsunami hazard impact in the land areas shown in Figure 7-5.

Table 7-2 Classification of economic impact for tsunami hazard

Economic Ranges ($M)	*Classification*
0-5	Negligible
5-60	Very low
50-100	Low
100-300	Moderate
300-600	High
>600	Very high

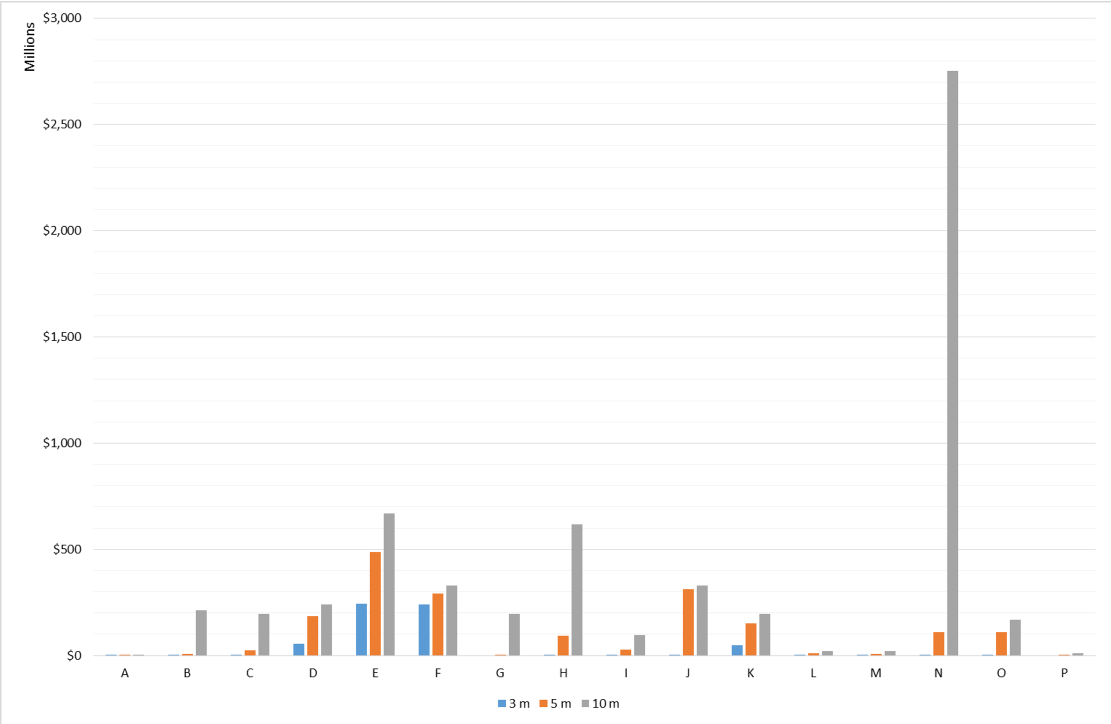

Figure 7-4: Economic losses by mapping unit for the tsunami hazard

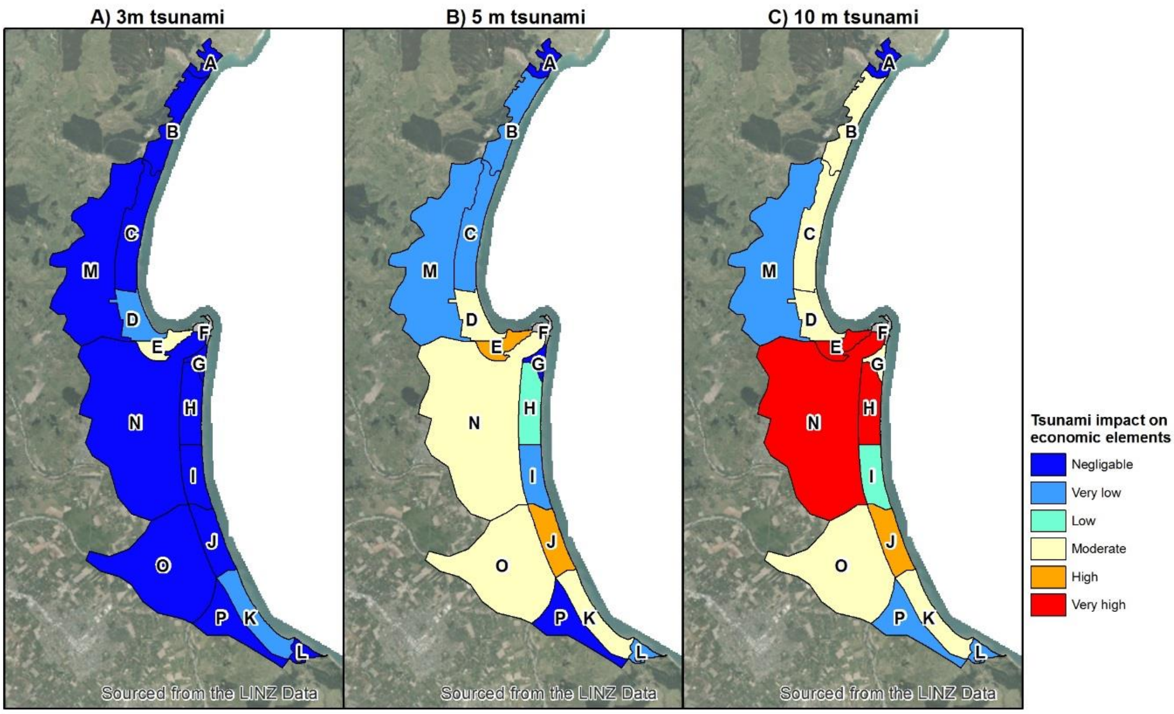

Figure 7-5: Economic impact for tsunami hazard

The risks are generally negligible-to-low for the 3 m tsunami, with only areas D, E and K being very low to low risk. The Napier city area (Mapping unit E, H and N) represent very high risk for the 10 meter tsunami hazard, while the urban and residential area along the shoreline have moderate risk during this event. Figure 7-6 shows the percentage increase in losses for the Napier City mapping units and area K (Haumoana/Te Awanga).

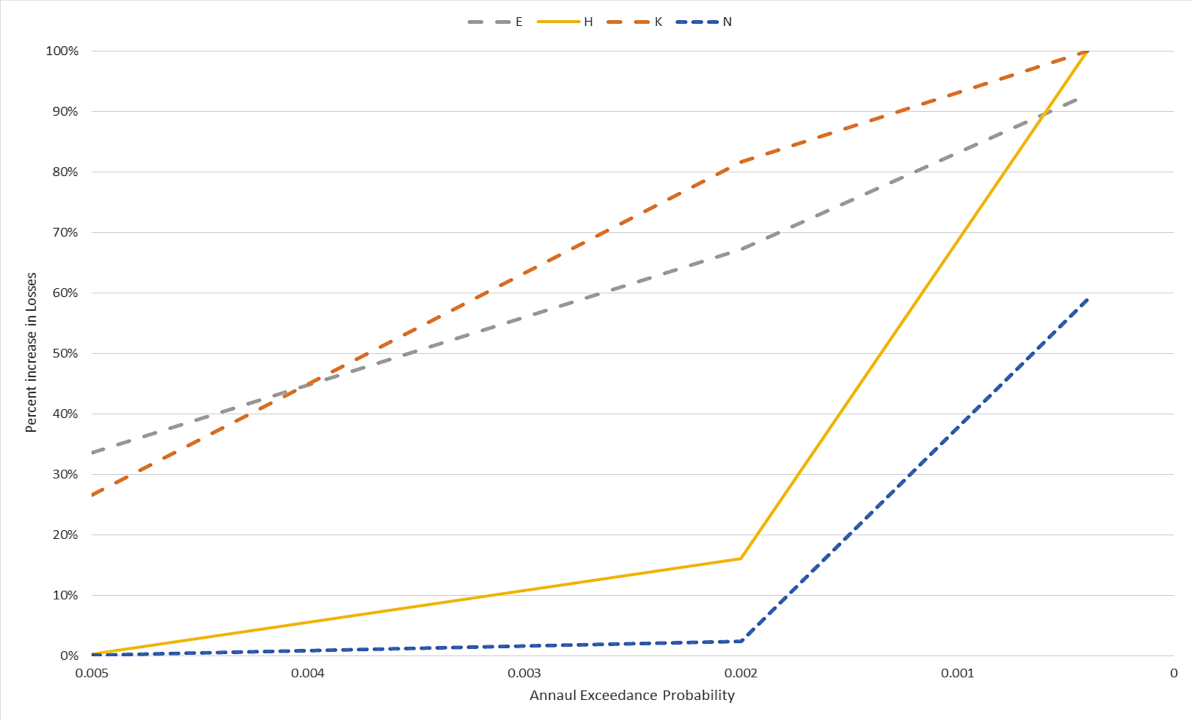

Figure 7-6: Percent increase losses for the hotspot land areas to tsunami hazard

This figure shows there is a gradual increase in losses for both area K and E from the 3 m to 10 m tsunami event. While at area H and N there is a slow increase in losses from the 3 m to 5 m tsunami and a significant increase in losses from the 5 m and 10 m tsunami. Tsunami hazard risk for different land areas is also shown in Appendix C (Figure C1).

7.2.2 Economic Losses for Coastal Inundation

Coastal inundation losses are classified into five classes shown in Table 7-3. This is a different scale to the tsunami assessment as the significant difference between the tsunami and other coastal hazards make it impractical to use the same scale. For example, if the tsunami scale was used, the majority of the impacts would be very low to low. The results for the three scenarios (10%, 1% and 0.5% AEP) for present day, 2065 and 2120 are shown in Figure 7-7. For AEP 1%, to assess the coastal inundation impact in the land areas is shown in Figure 7-8.

Table 7-3 Classification of economic impact for inundation and erosion hazard

Economic Ranges ($M)	*Classification*
<1	Negligible
1-5	Very low
5-30	Low
30-60	Moderate
60-100	High
>100	Very high

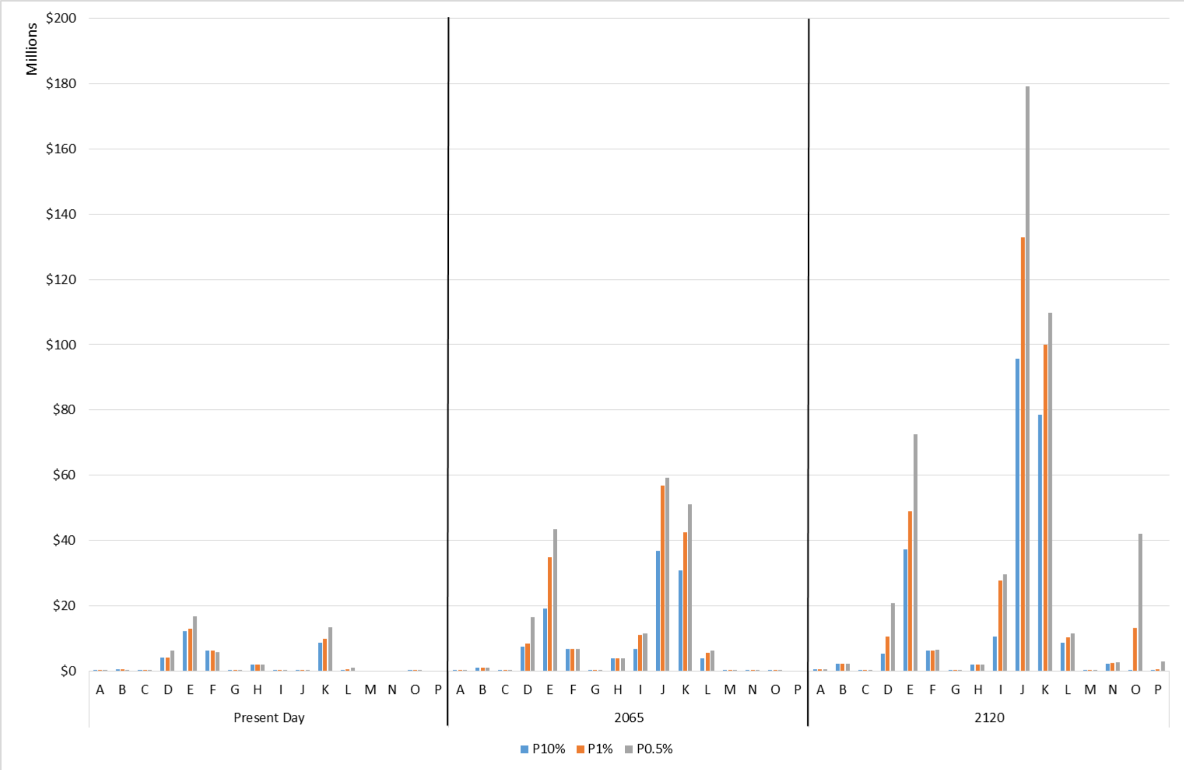

Figure 7-7: Economic losses of land areas by mapping unit under inundation hazard

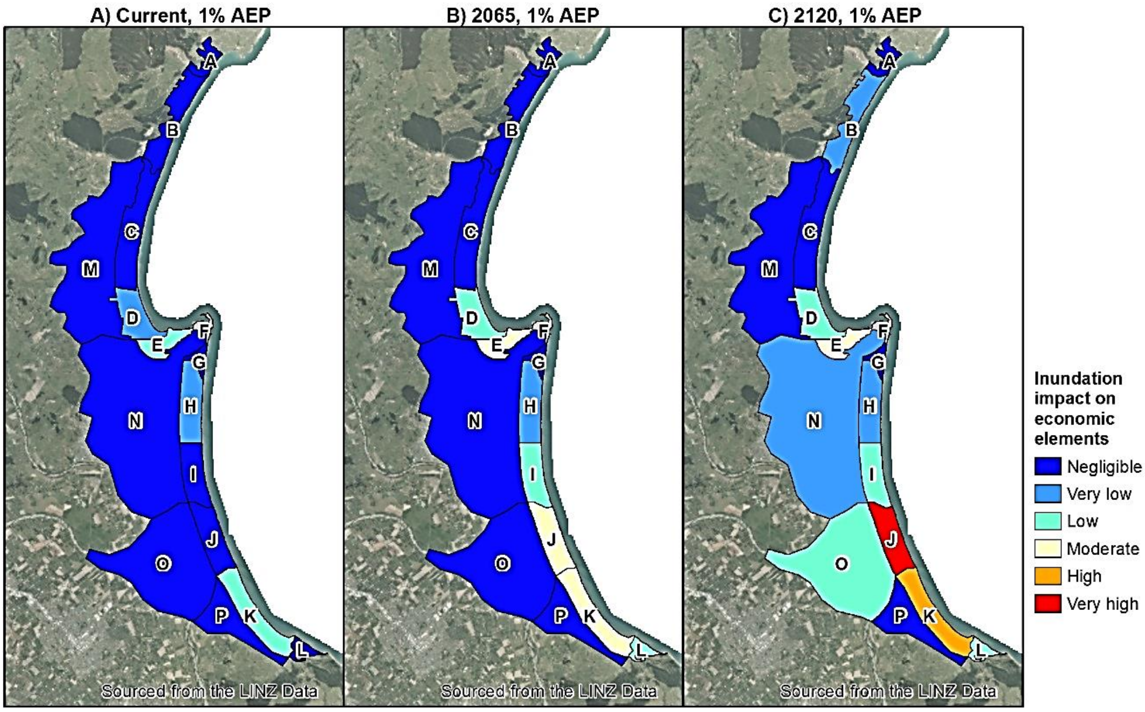

Figure 7-8: Economic impact in land areas of inundation hazard

The losses increases for coastal inundation from 2065 to 2120 significantly. Losses increase from 40% to 70% in mapping area J and K (East Clive, Haumoana/ Te Awanga area) which are flood prone areas comprising small residential settlements and a water treatment plant in area J. These hotspot areas are distributed in annual exceedance probability shown in Figure 7-9.

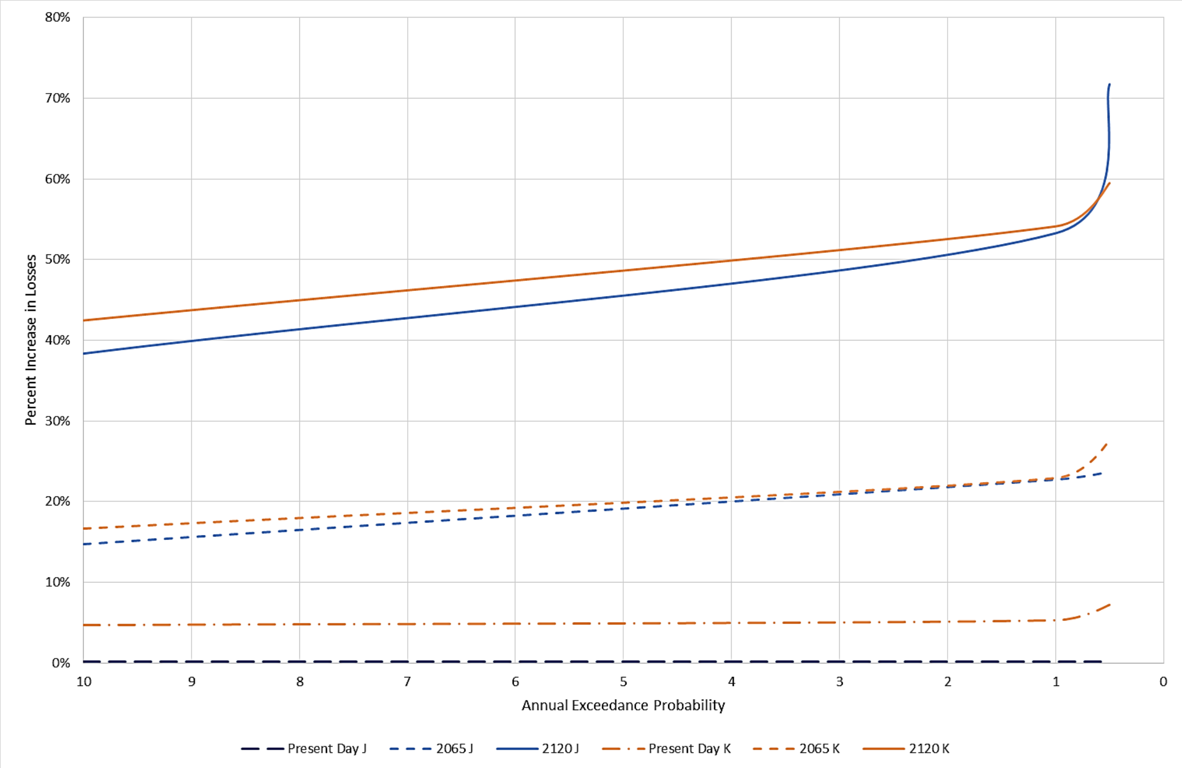

Figure 7-9: Annual exceedance probability for the hotspot land areas to inundation hazard

The increase of losses for mapping unit J increases significantly for AEP 1% to AEP 0.5%.

The land area classification for inundation hazard indicates the rural and urban residential risk is more prominent in 2065 and 2120 for all scenarios shown in Appendix C (Figure C2).

7.2.3 Economic Losses for erosion

For erosion, results for the four scenarios (66%, 33%, 5% and 1% AEP) for present day, 2065 and 2120 are shown in Figure 7-10. For AEP 1%, losses are classified into similar five classes shown in Table 7.3 for inundation to assess the coastal erosion impact in the land areas shown in Figure 7-11.

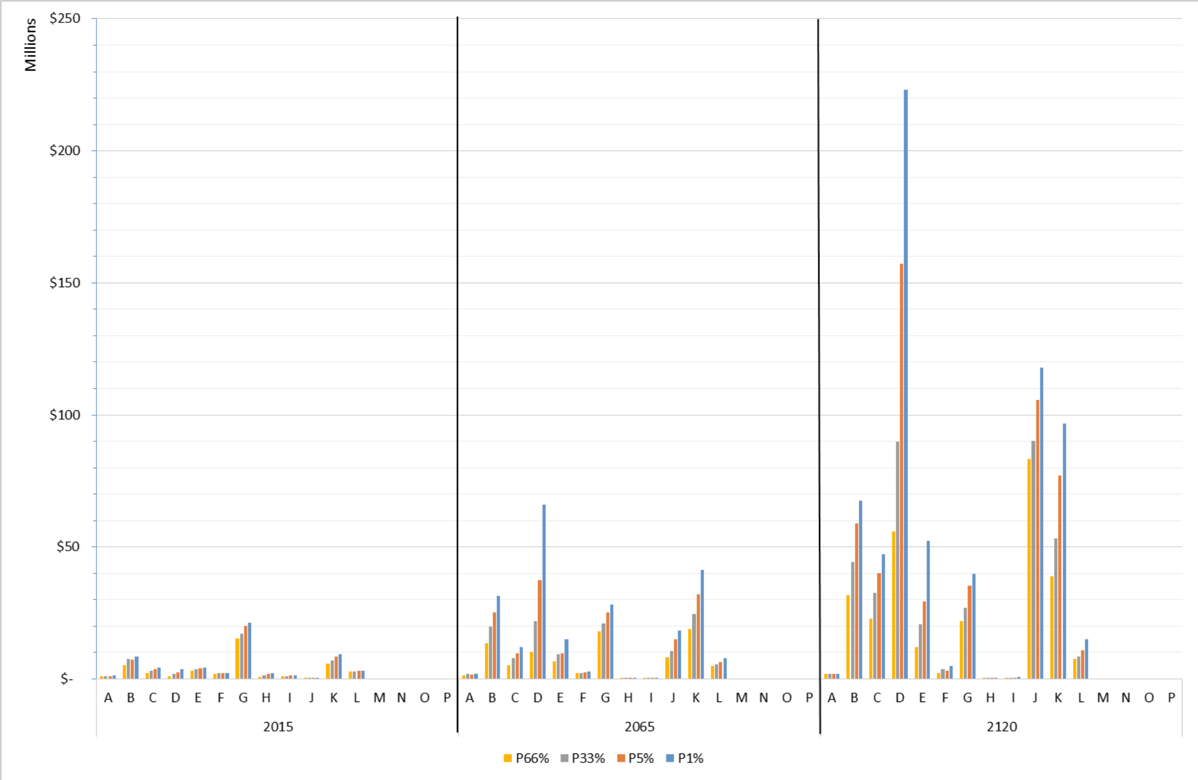

Figure 7-10: Economic losses of land areas by mapping unit under erosion hazard

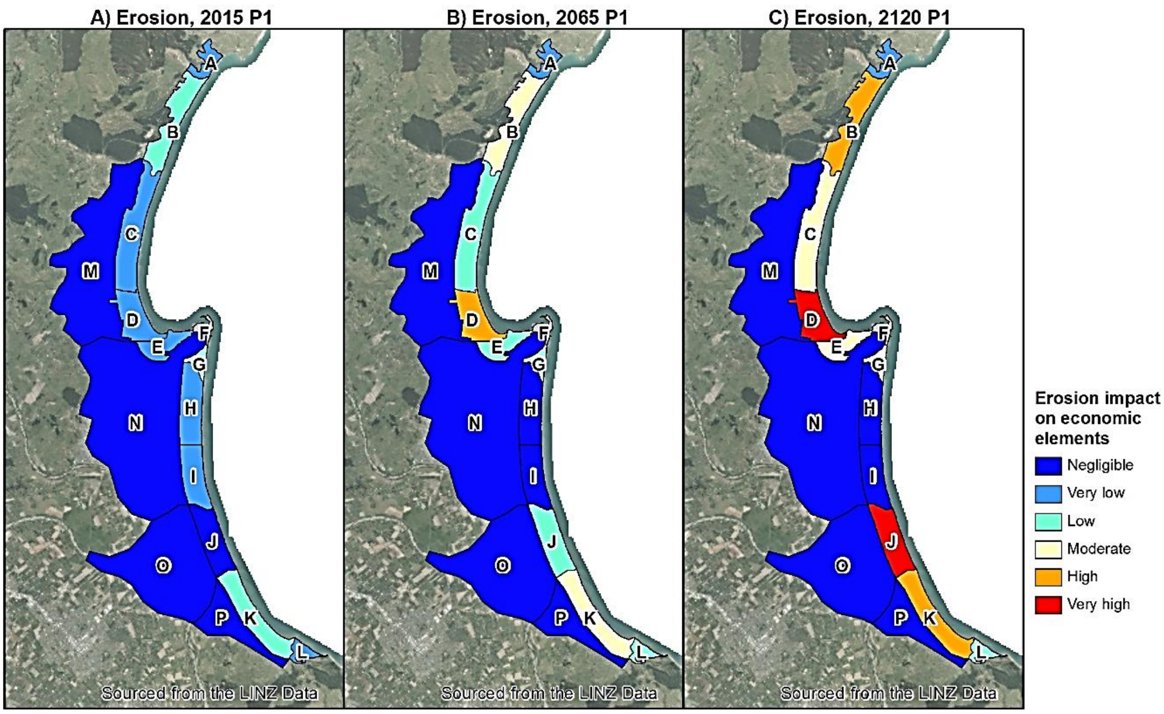

Figure 7-11: Economic impact in land areas of erosion hazard

The mapping area D, J and K are highly vulnerable for future scenarios for erosion. For AEP 1% scenario losses increase $65 million for map unit D in year 2120. The hotspot area D, J and K are shown in annual exceedance probability in Figure 7-12.

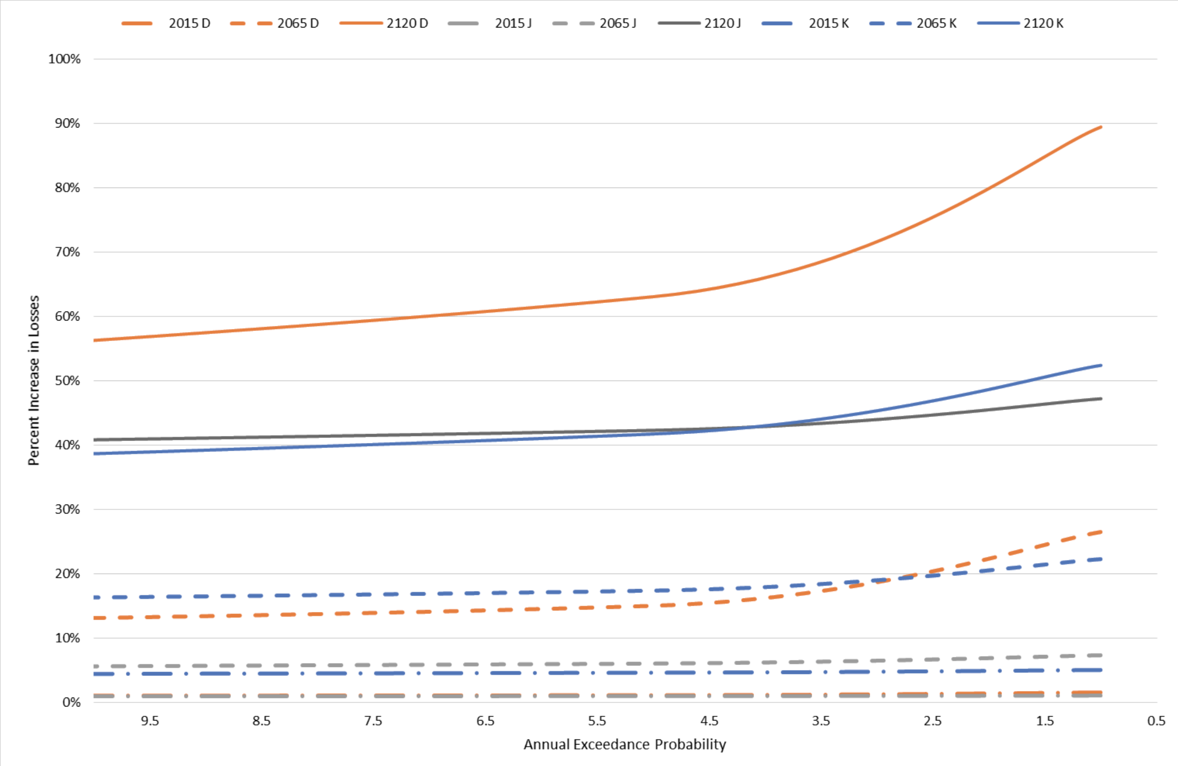

Figure 7-12: Percent increase losses for the hotspot land areas to erosion hazard

Erosion hazard risk for different land areas also shown in the Appendix C (Figure C3). Urban and rural residence are highly at high risk for erosion hazard.

7.3 Social/cultural losses

While social and cultural assets include economic objects (buildings), this category focuses on non-monetary loss and is based on vulnerability and exposure scale (low 1% to 30%, Moderate 30% to 70%, high 70% to 90% and very high > 90%). Building values are included in the economic loss category.

7.3.1 Social/cultural losses for tsunami

For tsunami, asset vulnerability is shown in Figure 7-13 based on water depth and impact in the land area. Figure 7-14 summarised the risk based on exposure.

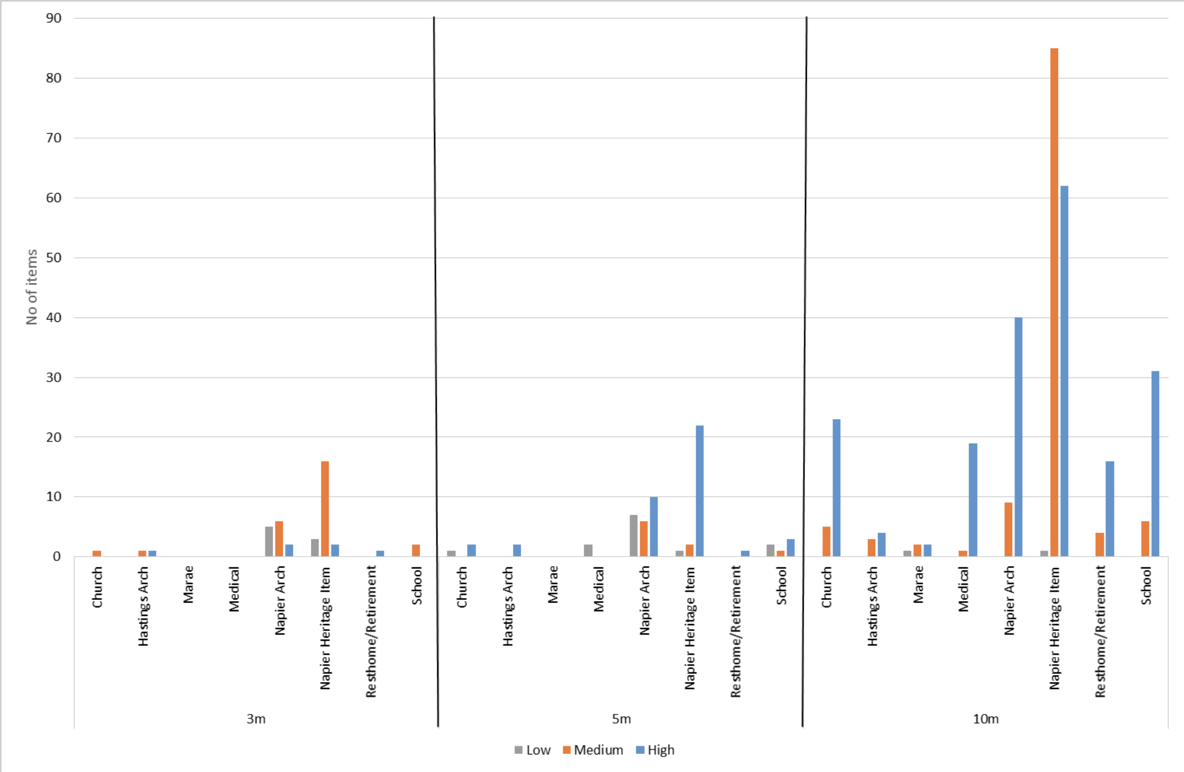

Figure 7-13: Social/cultural assets vulnerability under tsunami hazard

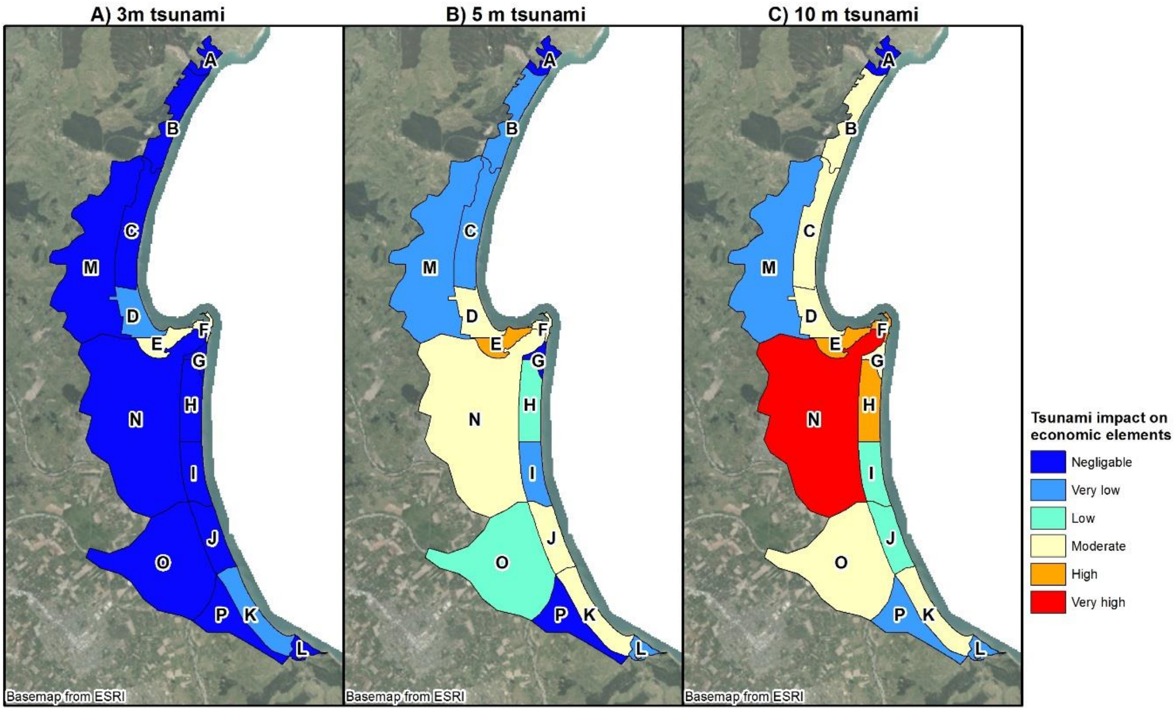

Figure 7-14: Social/cultural impact in land areas of tsunami hazard

Churches, schools, Napier Archaeological and Napier Heritage items are highly vulnerable for tsunami hazard.

7.3.2 Social/cultural losses for coastal inundation

Assets vulnerability under inundation hazard are shown in Figure 7-15 and exposure based impact per land area is shown in Figure 7-16.

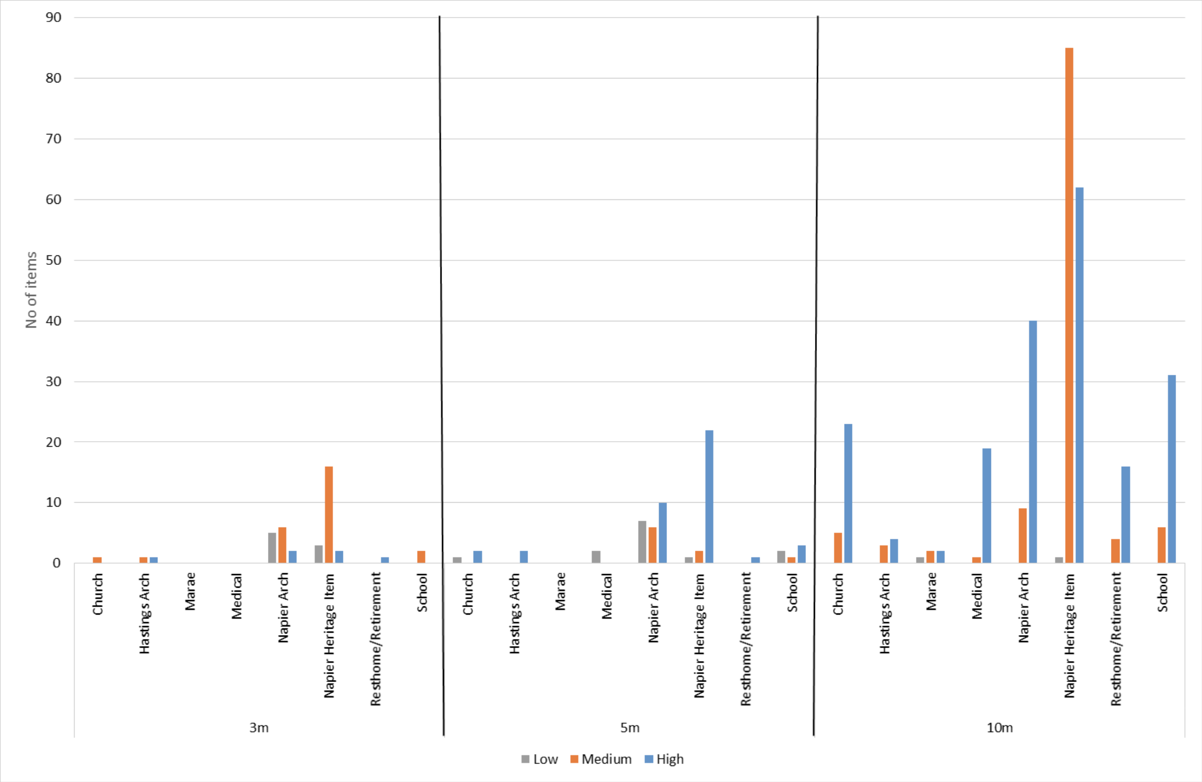

Figure 7-15: Social/cultural assets vulnerability under inundation hazard

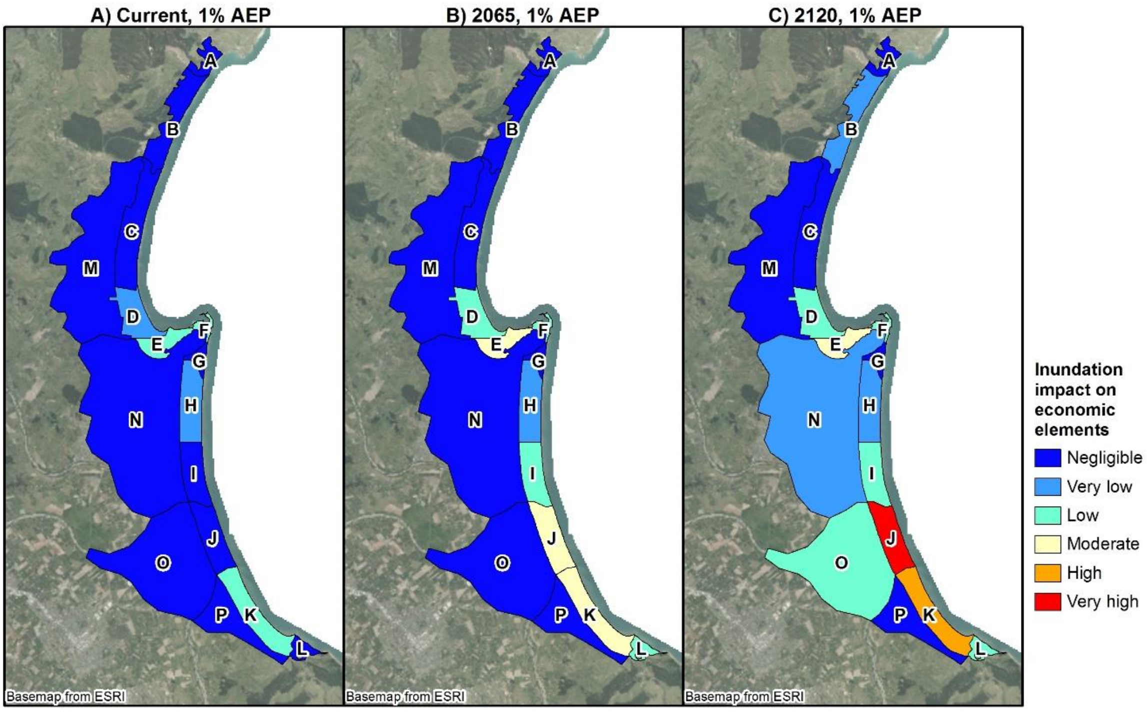

Figure 7-16: Social/cultural impact in land areas of inundation hazard

Except mapping area L where there is a camp ground, all others areas have a low to moderate risk.

7.3.3 Social/cultural losses for erosion

Erosion impact for social/cultural losses are shown in Figure 7-17.

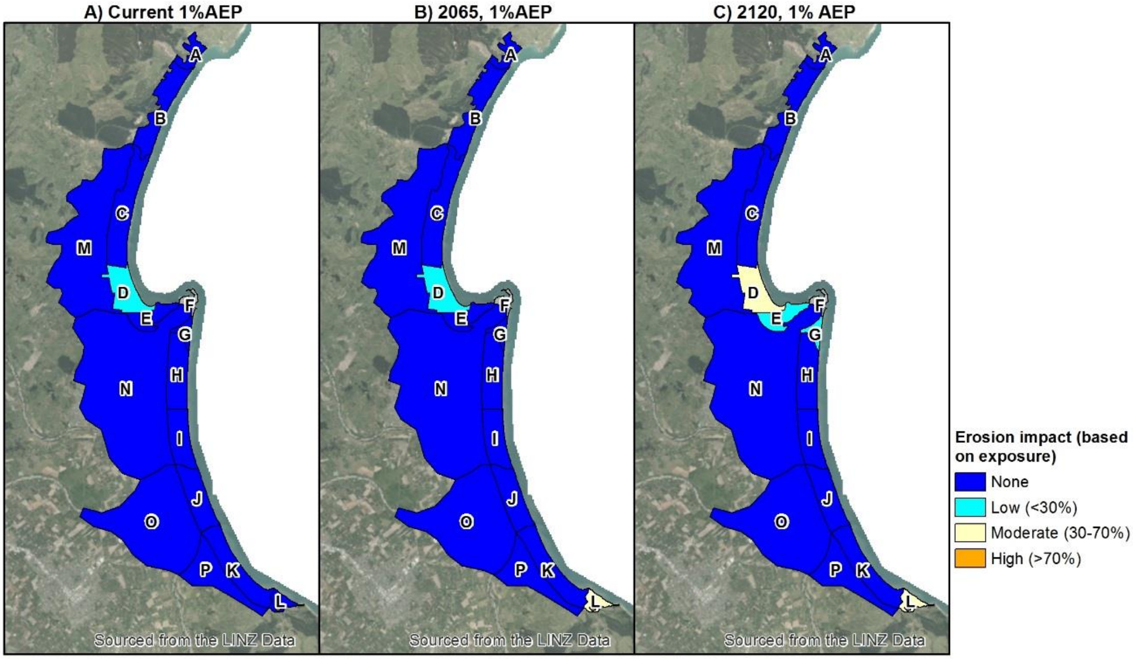

Figure 7-17: Social/cultural impact in land areas of erosion hazard

Mapping area D, E, G and L shows low to moderate impacts for erosion.

7.4 Environmental/ecological losses

The risk assessment for these categories is based on exposure for land areas identified by council as significant conservation areas. The environmental/ecological losses for tsunami and coastal inundation shown in Figure 7-18 and Figure 7-19 respectively. No figure is presented on the risks resulting from coastal erosion as there are no significant risks of coastal erosion on the environment/ecological losses.

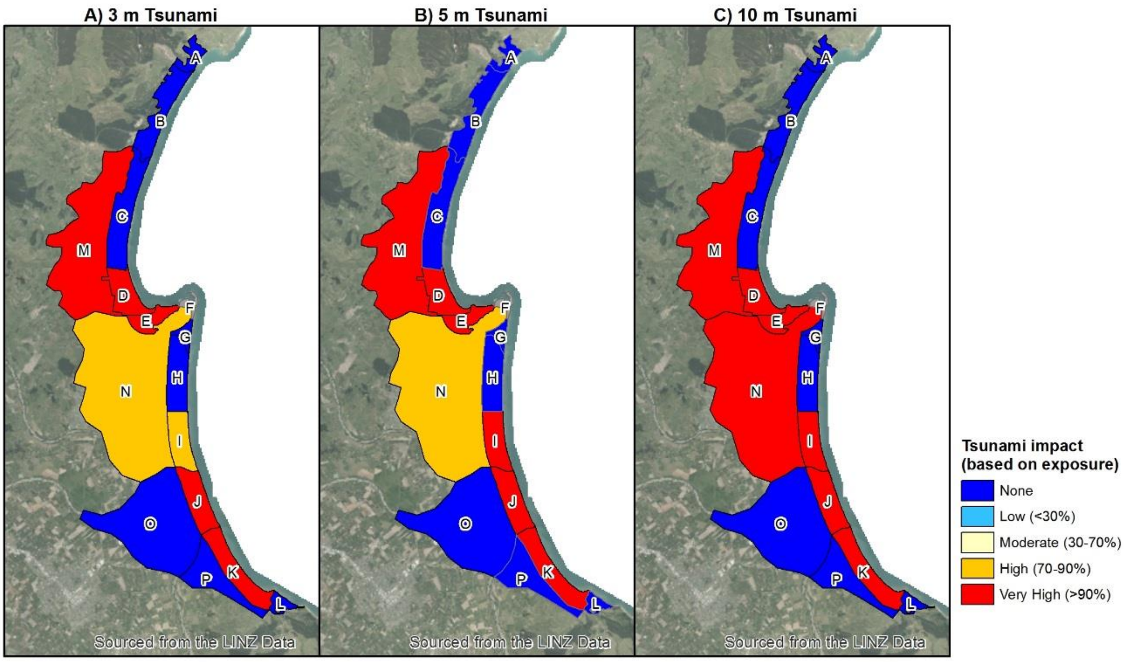

Figure 7-18: Impact on ecological and environmental aspects of tsunami hazard

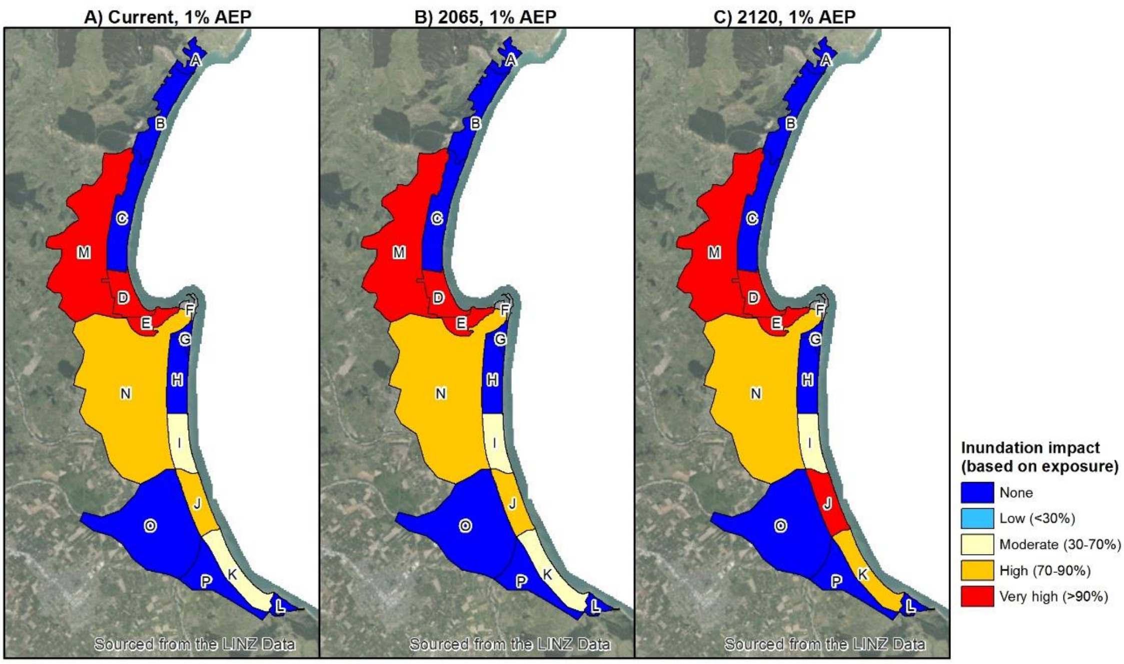

Figure 7-19: Impact on ecological and environmental aspects of 1%AEP coastal inundation hazard

The environmental impact for tsunami and coastal inundation has moderate to very high risk in the wetland and river mouth entrances.

7.5 Summary

The summary of risk classification for tsunami, coastal inundation and erosion are set out in Table 7-4 to Table 7-6 with results shown in terms of effects on humans (fatalities and injuries), economic, social and cultural and environmental/ecological for the 15 mapping areas using the same colour scale classification as shown in the plots earlier in this section.

Table 7-4: Summary of tsunami risk classification

Mappin	3 m Tsunami				5 m Tsunami				10 m tsunami			
g unit	Human	Economic	Social/cul	Env/ecol	Human	Economic	Social/cul	Env/ecol	Human	Economic	Social/cul	Env/ecol
A	Very low	Negligible	None	None	Very low	Negligible	None	None	Very low	Negligible	None	None
B	Low	Negligible	Moderate	None	Low	Very low	Moderate	None	Moderate	Moderate	Moderate	None
C	Moderate	Negligible	None	None	Moderate	Very low	Low	None	Large	Moderate	Moderate	None
D	Large	Very low	Moderate	Very high	Large	Moderate	Very high	Very high	Large	Moderate	Very high	Very high
E	Large	Moderate	High	Very high	Large	High	High	Very high	Very large	Very high	Very high	Very high
F	Low	Moderate	None	None	Low	Moderate	None	None	Low	High	None	None
G	Low	Negligible	None	None	Low	Negligible	Low	None	Moderate	Moderate	Moderate	None
H	Moderate	Negligible	None	None	Moderate	Low	Low	None	Very large	Very high	Very high	None
I	Low	Negligible	Moderate	High	Low	Very low	Very high	Very high	Low	Low	Very high	Very high
J	Moderate	Negligible	None	Very high	Moderate	High	None	Very high	Large	High	None	Very high
K	Large	Very low	None	Very high	Large	Moderate	None	Very high	Large	Moderate	None	Very high
L	Low	Negligible	Moderate	None	Low	Very low	Moderate	None	Low	Very low	Very high	None
M	Low	Negligible	Low	Very high	Low	Very low	Low	Very high	Moderate	Very low	Low	Very high
N	Moderate	Negligible	Low	High	Moderate	Moderate	Low	High	Very large	Very high	Moderate	Very high
O	Moderate	Negligible	None	None	Moderate	Moderate	None	None	Large	Moderate	Moderate	None
P	Very low	Negligible	None	None	Very low	Negligible	None	None	Low	Very low	Low	None

Table 7-5: Summary of coastal inundation risk classification

Mappin	1% AEP inundation, Current				1% AEP, 2065				1% AEP, 2120			
g unit	Human	Economic	Social/cul	Env/ecol	Human	Economic	Social/cul	Env/ecol	Human	Economic	Social/cul	Env/ecol
A	Very low	Negligible	None	None	Very low	Negligible	None	None	Very low	Negligible	None	None
B	Very low	Negligible	Moderate	None	Very low	Negligible	Moderate	None	Very low	Very low	Moderate	None
C	Very low	Negligible	None	None	Very low	Negligible	None	None	Very low	Negligible	None	None
D	Very low	Very low	Low	Very high	Very low	Low	Low	Very high	Very low	Low	Low	Very high
E	Very low	Low	Low	Very high	Very low	Moderate	Low	Very high	Very low	Moderate	Low	Very high
F	Very low	Low	None	None	Very low	Low	None	None	Very low	Low	None	None
G	Very low	Negligible	None	None	Very low	Negligible	None	None	Very low	Negligible	Low	None
H	Very low	Very low	Low	None	Very low	Very low	Low	None	Very low	Very low	Low	None
I	Very low	Negligible	Moderate	Moderate	Very low	Very low	Moderate	Moderate	Very low	Low	Moderate	Moderate
J	Very low	Negligible	None	High	Very low	Moderate	None	High	Very low	Very high	None	Very high
K	Very low	Low	None	Moderate	Very low	Moderate	None	Moderate	Very low	High	Moderate	High
L	Very low	Negligible	None	None	Very low	Low	Moderate	None	Very low	Low	Moderate	None
M	Very low	Negligible	Low	Very high	Very low	Negligible	Low	Very high	Very low	Negligible	Low	Very high
N	Very low	Negligible	None	High	Very low	Negligible	None	High	Very low	Very low	None	High
O	Very low	Negligible	None	None	Very low	Negligible	None	None	Very low	Low	None	None
P	Very low	Negligible	None	None	Very low	Negligible	None	None	Very low	Negligible	None	None

Table 7-6: Summary of coastal erosion risk classification

Mapping	P1%, Current				P1%, 2065				P1%, 2120			
unit	Human	Economic	Social/cult	Env/ecol	Human	Economic	Social/cult	Env/ecol	Human	Economic	Social/cult	Env/ecol
A	Very low	Very low	None	None	Very low	Very low	None	None	Very low	Very low	None	None
B	Very low	Low	None	None	Very low	Moderate	None	None	Very low	High	None	None
C	Very low	Very low	None	None	Very low	Low	None	None	Very low	Moderate	None	None
D	Very low	Very low	Low	None	Very low	High	Low	None	Very low	Very high	Moderate	None
E	Very low	Very low	None	None	Very low	Moderate	None	None	Very low	Moderate	Low	None
G	Very low	Low	None	None	Very low	Low	None	None	Very low	Moderate	Low	None
H	Very low	Very low	None	None	Very low	Negligible	None	None	Very low	Negligible	None	None
I	Very low	Very low	None	None	Very low	Negligible	None	None	Very low	Negligible	None	None
J	Very low	Negligible	None	None	Very low	Low	None	None	Very low	Very high	None	None
K	Very low	Low	None	None	Very low	Moderate	None	None	Very low	High	None	None
L	Very low	Very low	None	None	Very low	Low	Moderate	None	Very low	Low	Moderate	None
M	Very low	Negligible	None	None	Very low	Negligible	None	None	Very low	Negligible	None	None
N	Very low	Negligible	None	None	Very low	Negligible	None	None	Very low	Negligible	None	None
O	Very low	Negligible	None	None	Very low	Negligible	None	None	Very low	Negligible	None	None
P	Very low	Negligible	None	None	Very low	Negligible	None	None	Very low	Negligible	None	None

The tsunami hazard risk within the Hawke Bay region is significantly greater than the coastal inundation and coastal erosion hazard in terms of all key elements – human, economic, social/cultural and environmental/ecological. Losses for coastal inundation are greater than coastal erosion, but the range of values are of a similar order of magnitude for these two hazards.

Human losses

Due to the short warning time for a near field tsunami and the magnitude of the events predicted, the tsunami hazard poses the greatest risk to human loss of life and injury, with all tsunami events modelled potentially able to cause both loss of life and injury. A 10 meter tsunami height will have greatest impact in the Napier City area due to the high population density and low-lying land. Potential fatalities of around 5,400 and injuries of around 4,600 are estimated for the 10 m tsunami. Loss of life is anticipated to be very low for coastal inundation and erosion as it is expected that a combination of better forecasting, early warning systems and approaches to manage future sea level rise will be more effective for these hazards.

Economic losses

The risks are generally negligible-to-low for the 3 m tsunami, with only areas D, E and K being at very low to low risk. The Napier city area (Mapping unit E, H and N) represent very high risk for the 10 meter tsunami hazard, while the urban and residential area along the shoreline have moderate risk during this event. Near the estuary (area E) and at the southern end of the area (area K) there is a gradual increase in losses from the 3 m to 10 m tsunami event due to the low lying nature of these areas. At area H and N there is a slow increase in losses from the 3 m to 5 m tsunami but a significant increase in losses from the 5 m and 10 m tsunami as existing defences are inundated by the tsunami.

In the present day coastal inundation losses are low. The losses increase significantly for coastal inundation from 2065 (up to moderate) and 2120 (up to very high risk). The greatest increase in loss occurs in areas E, I, J and K. Area I to K represents the East Clive to Clifton area which is flood prone and comprise small residential settlements and Hastings water treatment plant. The increase of losses increases significantly from 1%AEP to 0.5% AEP events. The land area classification indicates the rural and urban residential risk is more prominent in 2065 and 2120 for all scenarios.

In the present day the coastal erosion hazard risk is generally very low to low, with area G (Napier City) and K (Haumoana/Te-awanga) being the most at risk. The mapping areas D, J and K are increasingly vulnerable for future scenarios for erosion reaching very high economic losses in 2120 in areas D, J and high losses in areas B and K. Urban and rural residence are highly at high risk for erosion hazard, with roading risk influencing area B.

Social/cultural losses

Churches, schools, Napier Archaeological and Napier Heritage items are highly vulnerable for tsunami hazard.

Napier Archaeological and Napier and Hastings Archaeological and Heritage items are highly vulnerable for coastal inundation hazard, although with the exception of mapping area L the other areas are of low to moderate risk.

Mapping areas D, E, and G show low to moderate losses for erosion, while area L shows moderate to high losses.

Environmental losses

The environmental impact for both tsunami and coastal inundation has moderate to very high losses in the land areas. There is no significant loss for coastal erosion.

8 Applicability

This report has been prepared for the benefit of Hawke's Bay Regional Council , Napier City Council and Hastings District Council with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

Tonkin & Taylor Ltd

Report prepared by:	Authorised for Tonkin & Taylor Ltd by:
....	....
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Richard Reinen-Hamill	Project Director
Lisa Nicol-Lind	

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Appendix A: Study area

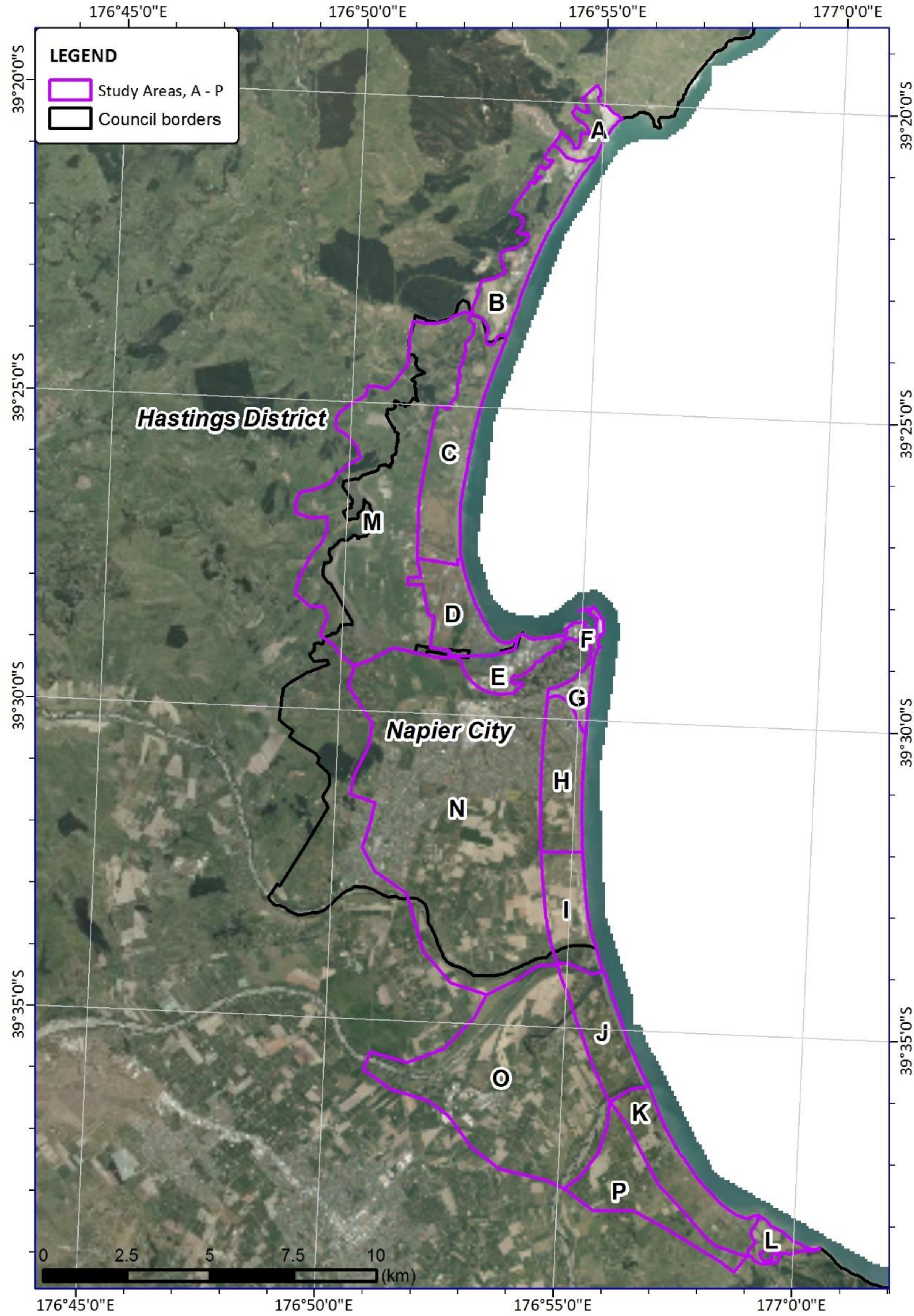

Figure A1: Study Area

Appendix B: Summary of elements at risk

Table B 1 Summary of elements at risk per mapping area

Map area	Value of lots (1000x$)					Main water services assets[1]	Airport (ha)	Road network (km)	Rail network (km)	Electrical, power and communications (dimension)	Napier Heritage buildings (No.)	Archaeological items (No.)	Environment items[2]	
	Residential (ResR & ResU)	Commerical (Com)	Industrial (Ind)	Rural (Rur)	Recreational (Rec)								No.	Area (ha)
A	12747	0	0	3712	0		-	5.7	-	-	-	1	-	-
B	400883	33830	0	36009	0	1	-	13.7	-	1	-	2	-	-
C	315888	5686	138	21087	2539	3	-	22.3	7.6	-	-	14	-	-
D	342186	3670	13755	40495	42362	5	107	14.71	3	-	-	6	1	42.7
E	508317	56490	653915	450	138045	4	-	18.8	14	-	27	4	1	54.1
F	11120	0	673602	825	213	-	-	2.6	2.3	-	-	1	-	-
G	257388	1380224	7090	0	195090	5	-	14.4	1.4	-	177	15	-	-
H	990576	9990	0	2610	105323	8	-	38	4	-	6	5	-	-
I	5575	0	155783	2390	48955	2	-	11.1	5.5	-	-	3	2	46.4
J	352324	0	0	12899	0	2	-	9.5	0.8	-	-	-	2	77.6
K	373699	2280	0	12230	0	4	-	17.7	0	-	-	2	1	19
L	78040	0	0	77856	0	-	-	2.1	0	-	-	3	-	-
M	174805	0	0	193187	0	1	-	32.2	1.8	-	1	89	1	78.2
N	6897600	289454	560936	714982	148127	41	-	235.9	4.3	-	22	38	1	5.9
O	210462	7560	70945	476611	0	-	-	43.7	6.6	-	-	5	1	26.9
P	75264	0	0	57348	0	-	-	11.4	0	-	-	4	-	-
Totals	**11006874.0**	**1789184.0**	**2136164.0**	**1652691.**	**680654.0**	**76**	**107**	**494**	**51**	**1**	**233**	**192**	**10**	**351**
1. pumping stations and treatments plants only							2. significant conservation areas and regional parks only							

Appendix C: Economic losses by land areas

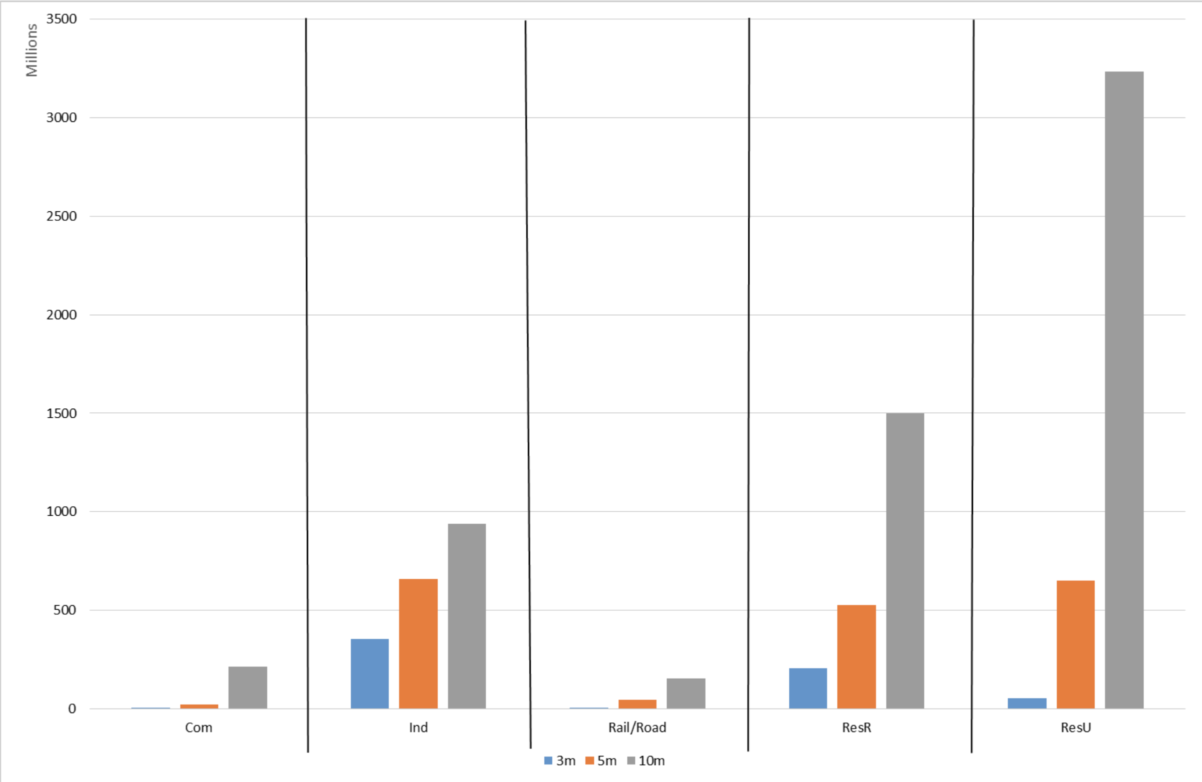

Figure C1: Total economic losses from tsunami hazard by land areas classification

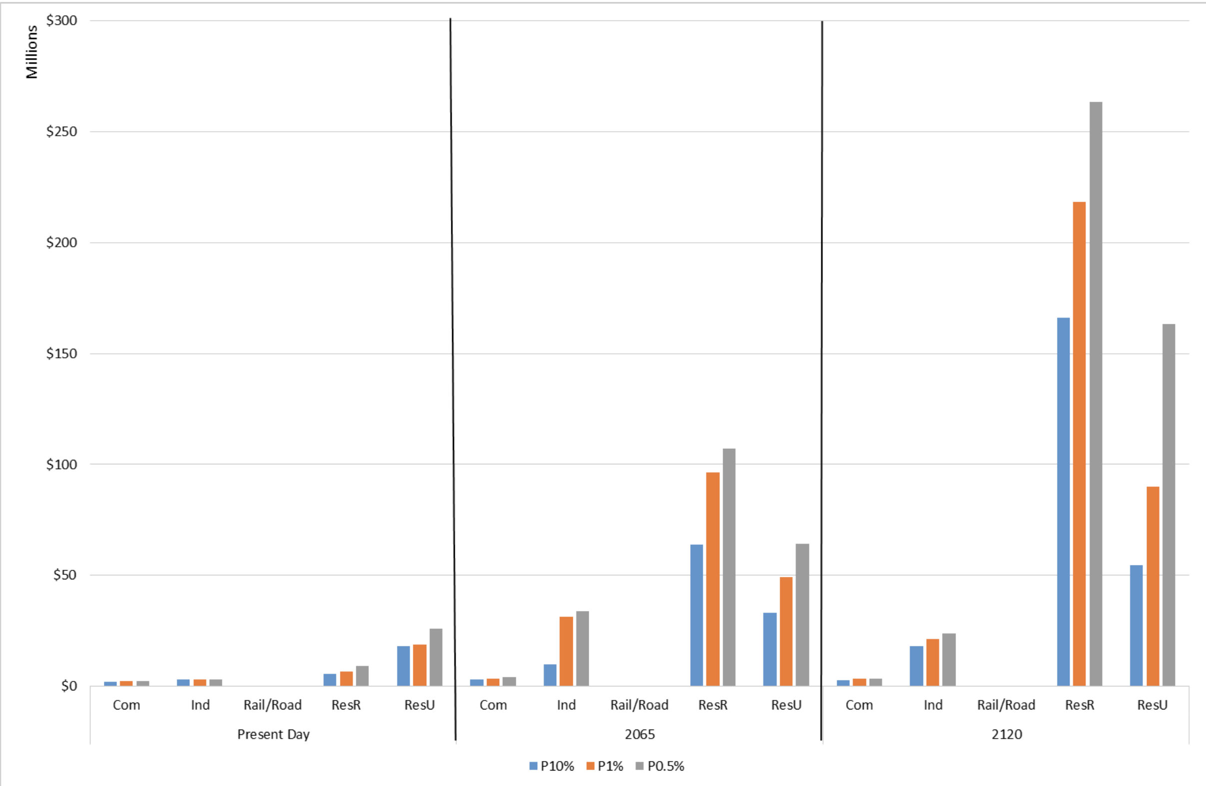

Figure C2: Total economic losses of land area to coastal inundation hazard by land areas classification

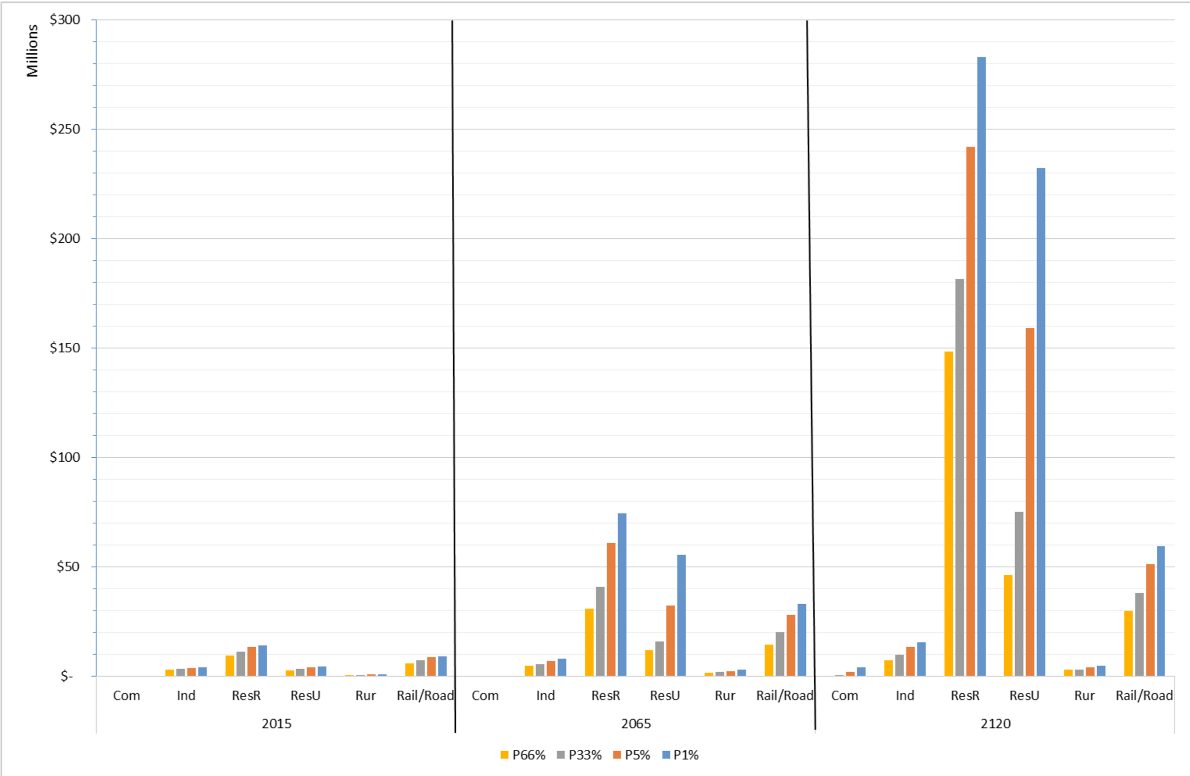

Figure C3: Economic losses of land area to coastal erosion hazard by land areas classification www.tonkintaylor.co.nz