MULTI-HAZARD ANALYSIS & MAPPING IN SUPPORT OF COASTAL CITY GROWTH PLANNING & RESILIENCE BUILDING

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HAZARD MODEL SETUP

Study Objective

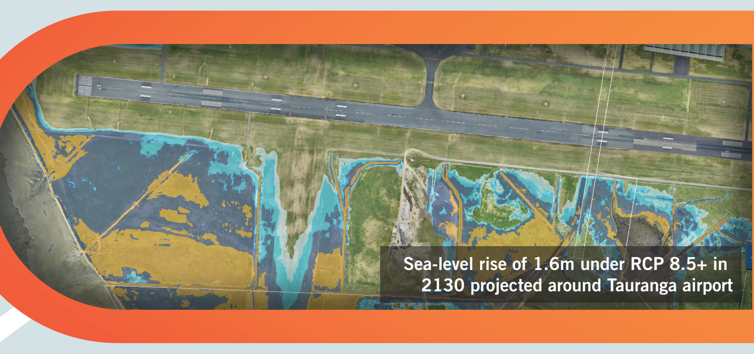
The objective is to develop a multi-hazard mapping technique to guide strategic growth planning in a natural hazard rich environment that gives direct comparison of total hazard levels across the city. This is particularly applicable where high growth is increasingly forcing development of hazard prone land

By aggregating individual hazards into a summative multi-hazard rating for each part of the city, urban planners and engineers have a decision support tool to aid city planning over the next 100 years.

The multi-hazard exposure is spatially mapped using GIS allowing an area with tsunami, liquefaction and storm surge as dominant hazards to be directly compared with an area of different hazards such as flooding and landslides. Mapping of these hazards provides strategic input for building city resilience through land use planning and mitigation design.

A pilot study area of 25km2 selected from the Tauranga City Council total area of 135 km2 demonstrates the accumulated mapping approach.

NATURAL HAZARD MAPPING

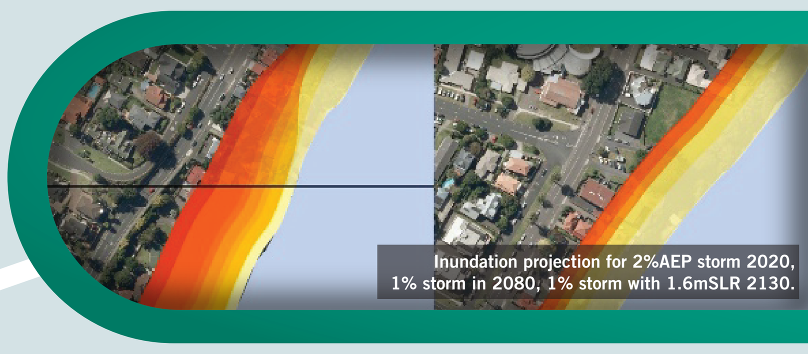


Sea-level rise of 1.6m under RCP 8.5+ in 2130 projected around Tauranga airport

Purpose	Year	SLR Projections for Tauranga based on IPCC 5 Scenarios			
		RCP 2.6	RCP 4.5	RCP 8.5	RCP 8.5H+
Baseline	1986-2005	0.07	0.07	0.07	0.07
Current	2020	0.13	0.13	0.13	0.13
Future	2080	-	0.4	0.6	-
Future	2130		0.8	1.25	1.6

Sea-Level Rise

- Mean sea level calibration was carried out in 2017
- 60mm rise since 1995 confirmed
- Sea level rise is projected from this baseline and adopt four RCP scenarios.

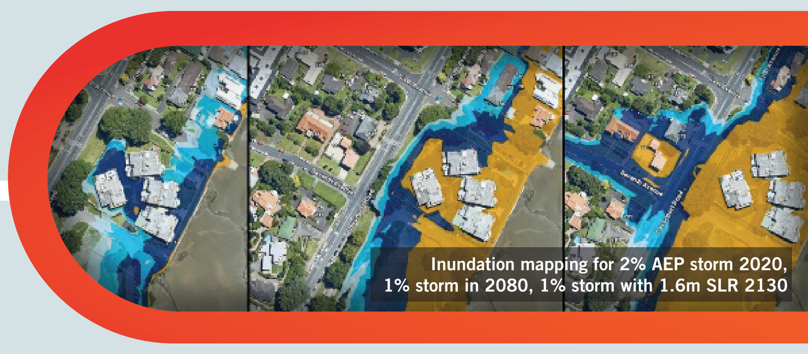


Inundation projection for 2%AEP storm 2020, 1% storm in 2080, 1% storm with 1.6mSLR 2130.

Input parameter	Coastline	SLR	Waves	Mapped Scenarios (m)						
Inner Harbour	Historical aerial photos 1943	Scenarios below		Current	2080			2130		
				Current MSL	0.4 SLR	0.6	0.6	0.8	1.25	1.6
Open Coast	As for inner harbour	As for inner harbour	Mild energy swell. Wave height up to 7.3m in a 1%AEP storm	Likely and very unlikely	Likely	Likely	Very unlikely	Likely	Likely & very unlikely	Very unlikely

Coastal Erosion

- Three environments mapped. Ocean coast, cliffs and estuary margins
- Probabilities mapped reflect levels of confidence or probability of exceedance
  - "Likely" represents 66%
  - "Highly unlikely" but still possible represents 5%

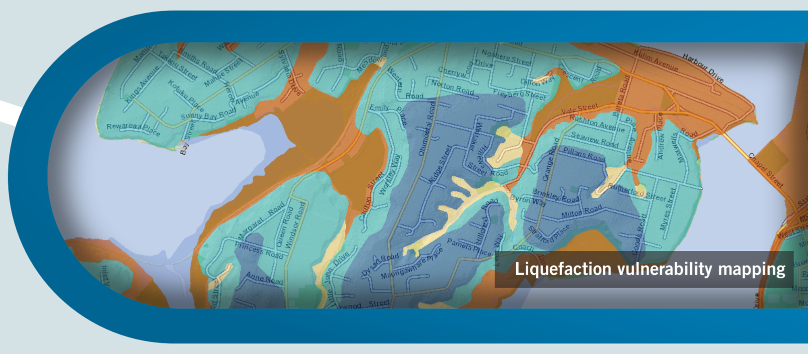


Inundation mapping for 2% AEP storm 2020, 1% storm in 2080, 1% storm with 1.6m SLR 2130

Scenarios mapped for Inundation	
Input parameter	**Description**
Base tidal scenario	Mean High water springs 7
Storn scenarios	2%, 1% and 0.2% AEP
SLR	Scenarios as above

Inundation

- Inundation due to storm surge modelled by NIWA (Stephens, 2018)
- Projections validated against actual storm in January 2018



Liquefaction vulnerability mapping

Liquefaction

- Mapped vulnerability and ground damage using MBIE documents
- 25-yr representing serviceability limit state requirements
- 100-yr and 250-yr showing interim liquefaction levels
- 500-yr representing ultimate limit state requirements

Liquefaction

Earthquake Shaking

- A city specific earthquake shaking PSHA (Bradley, 2019) underpinned liquefaction analysis

Other hazards included

Flooding
Mapped by catchment for multiple return periods

Landslides Static
Slopes mapped to represent hazard. No probabilities associated

Tsunami
Red, orange and yellow evacuation zones adopted

TRANSFORM AND COMBINE

Normalise for Impact / Factor for probability / Rate for exposure

Hazard Aggregation

The aggregated hazard at each point of the city was achieved by combining output from each individual hazard into a summative multi-hazard model. Each point is rated according to the accumulated number and scale of individual hazards, providing a multi-hazard exposure for that point. The resultant map provides a visual interpretation of the accumulated hazard

- Define exposure levels to each hazard and apply a 10-point scale hazard schema. Application of an additional schema factor will be necessary for hazards mapped with different return periods and timescales
- Define weighting coefficient to normalize individual hazards for balanced aggregation
- Sum normalized schema to obtain numerical representation of aggregated exposure (EHM)
- Geospatially map multi-hazard ratings in GIS
- $E_{HM} = \sum_{H_n}^{H_1} HS \times SF \times N$

Ehm Multi-hazard Exposure
Hn individual hazard
HS hazard schema 10 point scale
SF schema factor for different return periods
N normalisation factor

Rate for Exposure

Assign a rating representing the exposure level at each spatial point to each hazard. This hazard schema (HS) is on a 10 point scale. Areas already exposed to the hazard at a short return period event were considered high exposure. Areas at the outer extents of exposure under a hazard scenario of 1% AEP and 1.25m SLR were considered lowest exposure.

Hazard Schema

Hazard	Events defining schema points assignment			
	High (10)	Medium	Low (1)	Max extent
Sea level rise (HSSLR)	Up to 0.4 SLR	50-yr projection 0.4m to 0.8m	100-yr projection 1.25m SLR	1.6m SLR
Inundation from Storm Surge (HSI)	10-yr projection 0.0m SLR 1% AEP storm	50-yr projection 0.6m SLR 1% AEP storm	100-yr projection 1.25m SLR 1% AEP storm	100-yr projection 1.25m SLR
Coastal erosion (HSC)	10-yr projection 0.0m SLR 5% exeedance probability (p5)	50-yr projection 0.6m SLR P66	100-yr projection 1.25m SLR P66	100-yr projection 1.25m SLR P66
Tsunami (HST)	Red evacuation zone		Yellow evacuation zone	Yellow zone inland extreme
Liquefaction (HSL)	Moderate-severe ground damage 0.0m SLR 0.2% Aep	0.0m SLR 0.2% Aep	100-yr projection Minor-moderate 1.25m SLR 0.2% Aep	100-yr projection Extent of minor-mo 1.25m SLR 0.2% Aep
Landslide (HSLS)	Within slip zone 2h:1v	Outside 2h:1v zone and inside 3h:1v slope or inside 4h:1v runout slide		Outside of defined zones
Flooding (HSF)	Current 1m depth 0.0m SLR 1% AEP storm	Current max 0.0m SLR 1% AEP storm	100-yr projection 1.25m SLR 1% AEP storm	100-yr projection 1.25m SLR 1% AEP storm

Normalise for Impact

Four characteristic factors are assessed and weighted to normalise the impact of each hazard.

		Speed of onset	Duration	Areal extent	Spacial dispersion
		Speed event becomes hazard	How long will event persist	Spacial extent likely	Spatial predictability
Hazard	N	1-slow fast-5	1-short long-5	1-limited spread-5	1-diffuse conc-5
Sea level rise (NSLR)	0.17	1	5	5	5
Inundation (NI)	0.12	2	5	2	3
Coastal erosion (NC)	0.13	2	5	2	3
Tsunami (NT)	0.16	4	2	4	5
Liquefaction (NL)	0.17	5	1	5	5
Landslides (NLS)	0.11	5	1	2	2
Flooding (NF)	0.12	3	3	3	4

Factor for Probability Variations

adjustment factors to account for different return periods where these were not aligned adequately from the hazard quantification study.

Hazard	Schema Factor (SF)	Hazard study return period	Basis of adjustment calculation
Tsunami	0.5	1,000 to 2,500-year Orange >2,5-year Yellow zone	Available data is based on long return period high magnitude events established for evacuation purposes. Factor was derived from ratio of PGA established for Taurana through the PSHA
Liquefaction	0.75	500-year	500-year adopted to give extent of liquefaction in post-activation condition. Factor wad derived from ratio of pga established through the PSHA

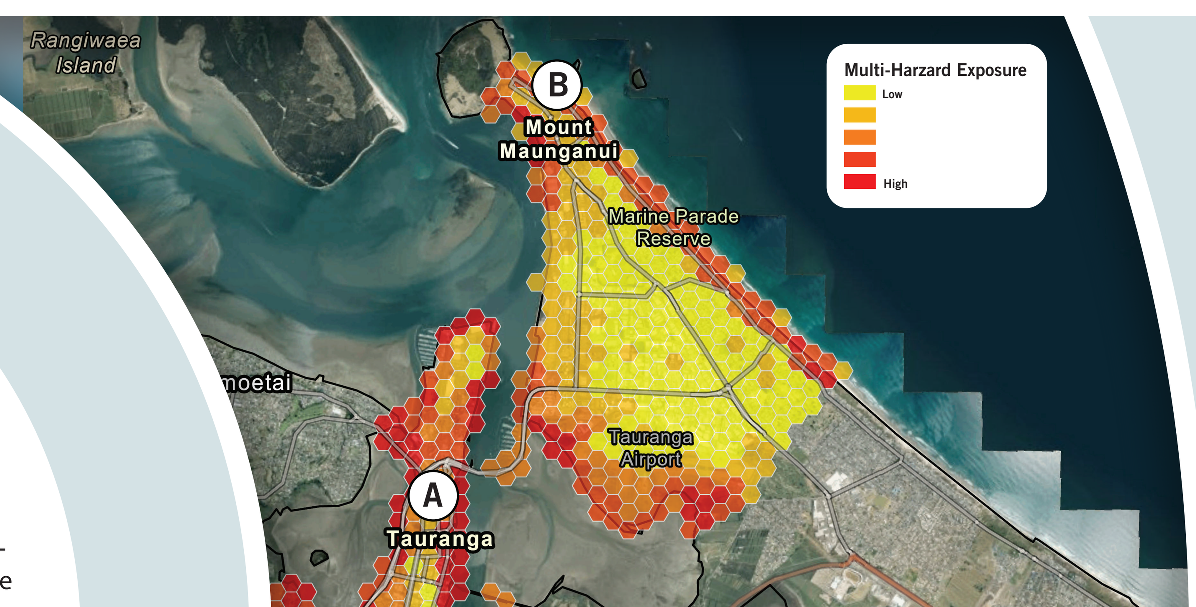
MULTI-HAZARD OUTPUT

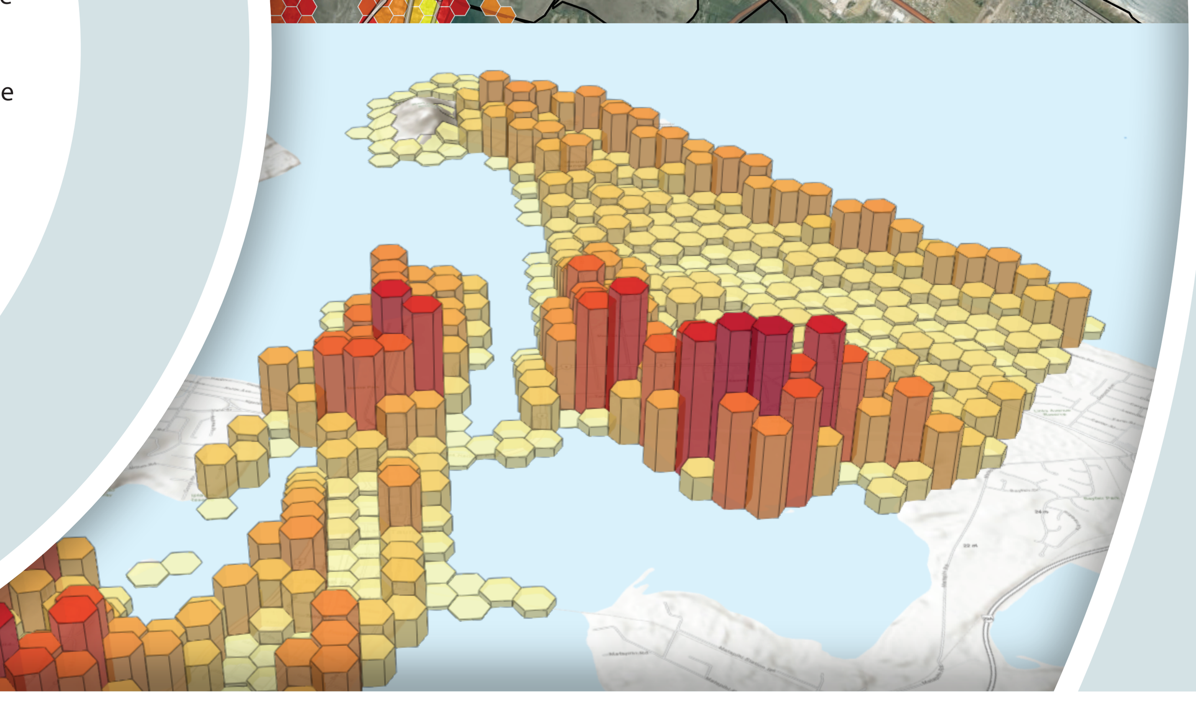
Conclusions

The mapping showed the highest aggregated hazard exposure are along the coast. As is common with many beach resort towns this corresponds with the most popular living areas. Lower hazard areas suitable for urban growth are on the slightly elevated peninsulas. Land-slide potential increases exposure further from the coast and along the peninsular margins.

Aggregated mapping of seven natural hazard appears unique in the number of hazards represented.

Based on this successful pilot it is proposed to expand the map to the whole city and incorporate improved graphic visualization.



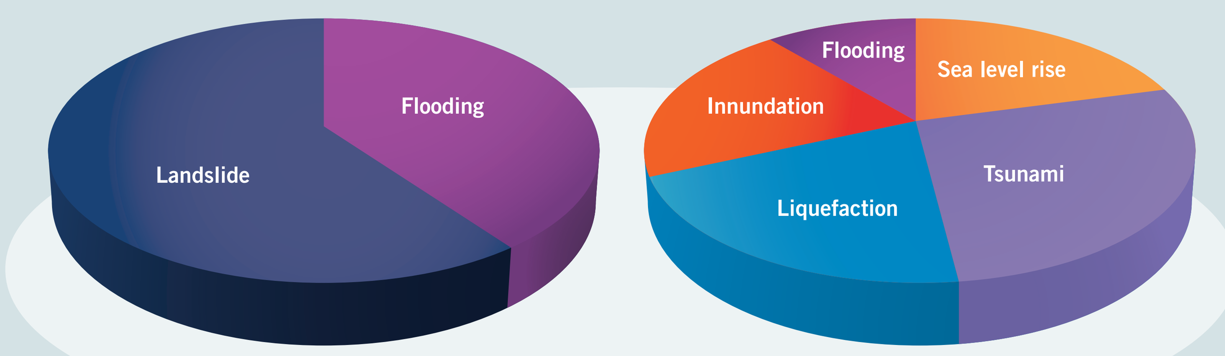


Results

Each part of the city was rated according to the overall number and scale of individual hazards and spatially mapped.

Total hazard level is graphically clarified through height and colour variations.

Verification was carried out by comparison with historical mapping and individual hazard maps.



Single point exposure contribution from points A and B