Indicative CBA Model for Earthquake prone building review

Summary of methodology and results

Final report - September 2012

MARTIN JENKINS

CBA Model

PURPOSE AND OUTPUTS

CBA Model: Purpose and Outputs

The purpose of the Model is to calculate the impact (costs and benefits) of possible changes to the earthquake prone building policy related to the target %NBS to be applied and the timing of compliance.

The model measures the incremental difference between a "status quo" position (assuming existing timeframes for compliance and the current 33% NBS target) and three Policy Options:

- A 33% NBS target but a shortening of the timeframe to comply
- A 67% NBS target – with or without a reset to the timeframe to comply, and
- A 100% NBS target – with or without a reset to the timeframe to comply.

For the status quo and each of the Policy Options, the model calculates costs and benefits for each Territorial Authority (TA) and sums the results to provide a total Cost/Benefit result for New Zealand.

In addition, the difference between the current policy and timing and a "no strengthening" option is also measured.

Costs that are modelled

- Building strengthening costs
- An option to include or exclude additional costs including Fire Safety and Disabled Access improvements

Benefits from strengthening that are modelled (i.e. reduced costs in the event of an earthquake)

- Reduced building damage
- Reduced loss of life
- Reduced injury

Outputs produced

- A present value net cost/benefit for each policy option – based on a 75 year modelling period and a range of earthquake sizes with specific probabilities for each earthquake in each TA.
- A cost/benefit result, as above, but measured for a single event annual earthquake and a single average probability factor.
- A "per event" cost/benefit for each policy option – assuming an earthquake actually occurs at set dates (eg at years 10, 15, 20, 30).

CBA Model: Purpose and Outputs

Other matters

Benefits do not include:

- Benefits from lower overall economic or social costs following an earthquake as a result of strengthening. (See the following page for reasoning behind this assumption).
- Rent increases as a result of strengthening (as these are already reflected in the measurement of benefits). If a tenant is asked to pay more rent due only to strengthening of their building, then they are effectively paying for the benefit of increased life safety and less damage should an earthquake occur. These benefits are already counted specifically in the CBA Model and to also count the rent increases (if any) would be to double-count this impact.

Benefits only accrue once strengthening has begun:

- Depending on the strengthening timetable, the benefits of strengthened buildings in the event of an earthquake only accrue after the work is completed. This means that benefits grow over the strengthening period and are at their maximum immediately after all buildings are strengthened.
- As the CBA Model measures the NPV of costs and benefits, total benefits decline each year after the end of strengthening due to annual discounting of the impacts. For example, the “benefits” accruing from an earthquake that occurs in year 25 have a greater present value than an earthquake of similar size that occurs in year 50.

Costs and Benefits are incremental.

- The CBA Model measures the annual <u>differences</u> between the current strengthening and timetable and the policy strengthening and timetables.

Why a 75 year model?

- 75 Years is seen as a conservative estimate of the remaining useful life of the current earthquake prone building stock. It is possible that building lives will be shorter, but using 75 years makes it more likely that all potential benefits are captured.

The CBA (cost-benefit analysis) provides just one piece of the information to be considered in developing the overall EPB policy. The results of the CBA should be used alongside all other policy factors and considerations.

CBA Model: Economic & social costs

Economic and social costs

The CBA Model has not included an estimate of benefits that might accrue, after an earthquake event, from lower overall economic or social costs as a result of having strengthened earthquake prone buildings (EPBs).

The basis for excluding such costs is as follows:

- Our assumption is that only very large earthquakes will cause economic or social costs (e.g. Christchurch was a 1 in 2,500 year earthquake). The probability of very large earthquakes is so low that any probability based benefits from strengthening buildings are small. Also, with very large earthquakes, the positive impact of a few strengthened EPBs is likely to be dwarfed by more significant impacts on infrastructure and residential dwellings. We would not expect to attribute much (if any) economic or social impacts to the demise or otherwise of EPBs.
- Similarly, in a large earthquake the damage to non-EPBs is likely to be large, and the damage to strengthened EPBs will also still be a major factor. These impacts may also dwarf whatever improvements may have been made by strengthening a small number of older buildings.
- If EPBs perform to design then in a large earthquake they should ensure that the occupants will survive. However, as evidenced in Christchurch, the buildings may still need to be demolished after the earthquake. It is this subsequent demolition that could cause an economic loss - and strengthening for the purpose of preserving life may do little to prevent this.
- There is likely to be a very narrow envelope of earthquake strengths where a strengthened EPB would remain standing and be useable after the event, but where it would not have survived if it hadn't been strengthened. This lowers the probability of there being a material reduction in impact on economic and social outcomes from strengthened EPBs compared to other impacts (such as infrastructure damage).
- A material impact (on a New Zealand scale) on economic and social outcomes after an earthquake is only likely to occur in cities/towns where there is a relatively high probability of a large earthquake and where there is a large commercial/industrial area. This is only the case in Wellington, Hutt City, Christchurch and Palmerston North.

CBA Model

NEW ZEALAND'S BUILDING STOCK

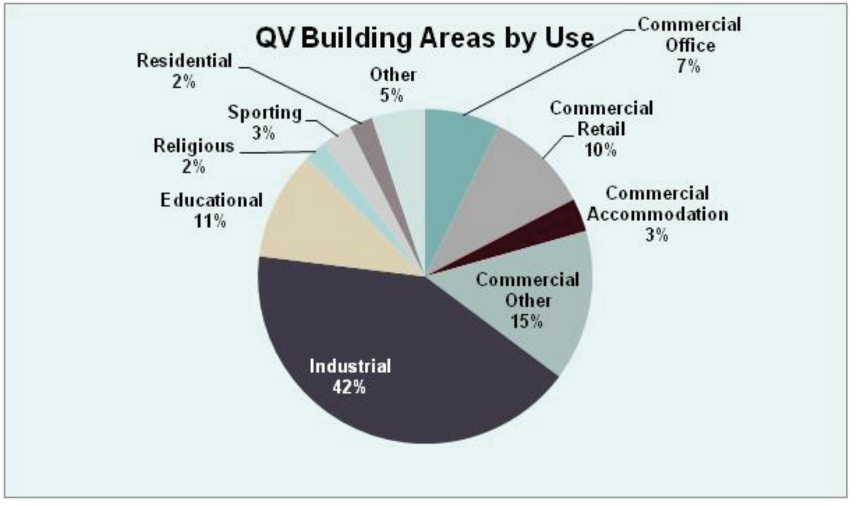
MARTIN JENKINS

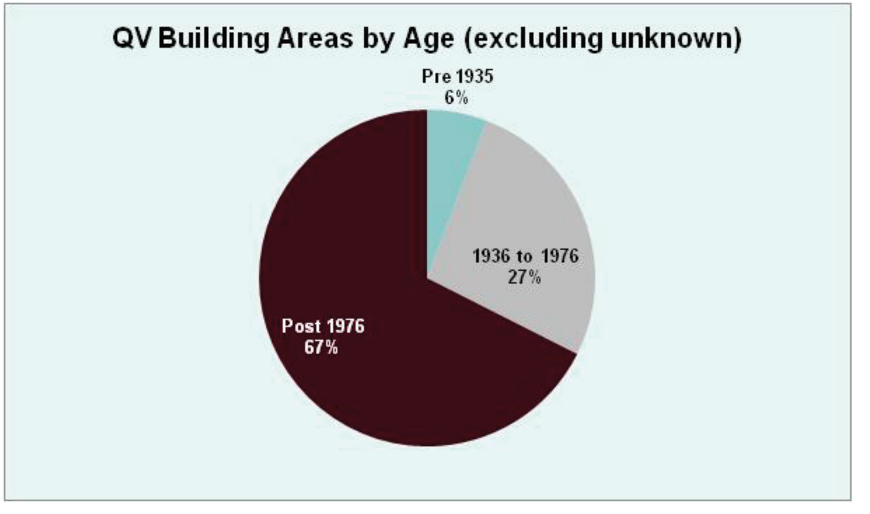
Total building stock

Total New Zealand building stock

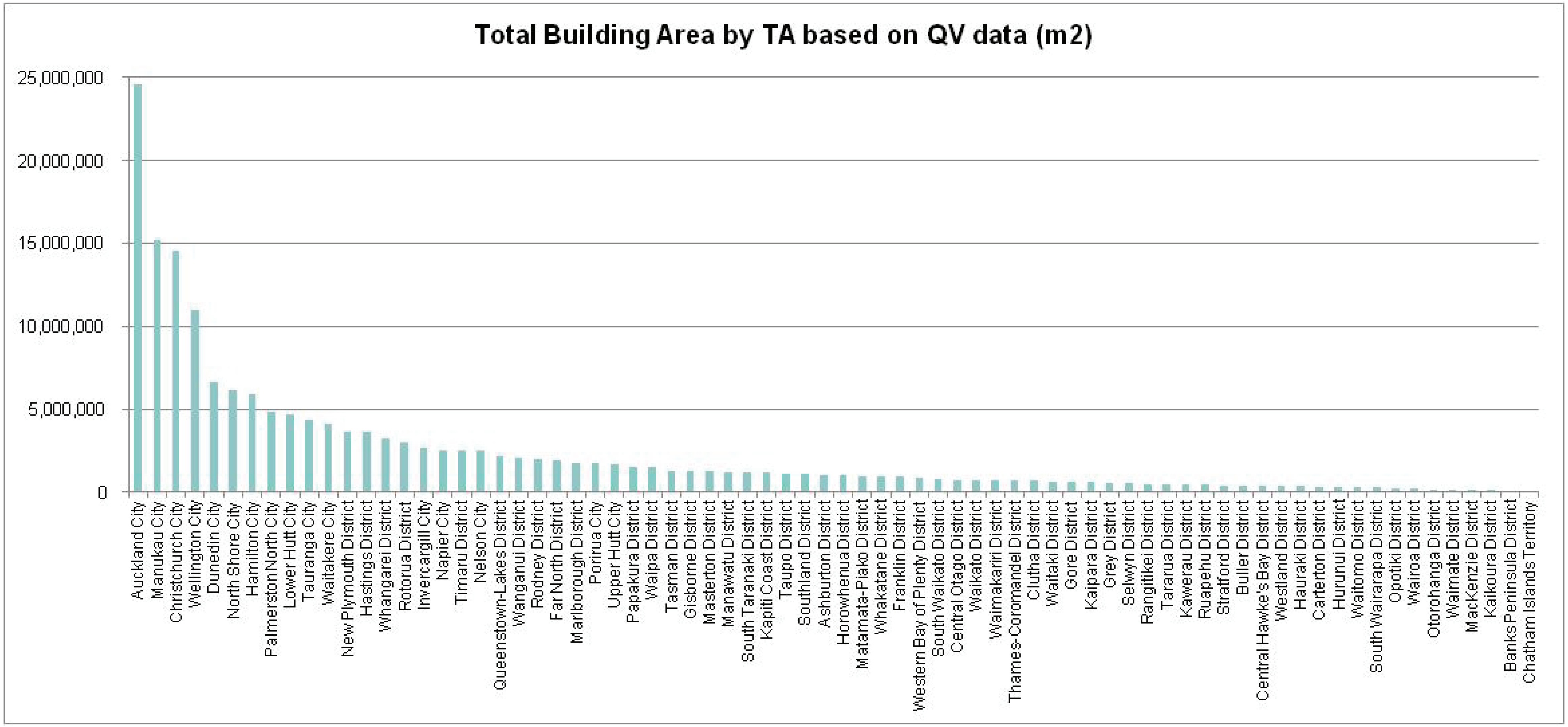
An estimate of the total building stock by location and age for commercial, industrial and other non-residential buildings, and high-rise residential buildings, was obtained from Quotable Value (QV).

- The data received from QV for numbers of buildings was higher than expected. It appeared that the data might include, in some cases, the numbers of units for multi-unit properties.
- QV were unable to easily separate out the actual building numbers from their database.
- As a result, building numbers have been reported as "buildings/units" in all model outputs and reports to take account of this possible issue with the QV data.
- Importantly, however, the CBA model bases the key calculations on the building area (rather than number) so the CBA Model is not affected by the recording of the number of buildings/units
- Note: 41% of buildings had age "unknown" because it was either not recorded or because the building was made up of several parts with different ages. These were allocated pro-rata in the model.
- The following charts show the make-up of the base data for all New Zealand buildings:





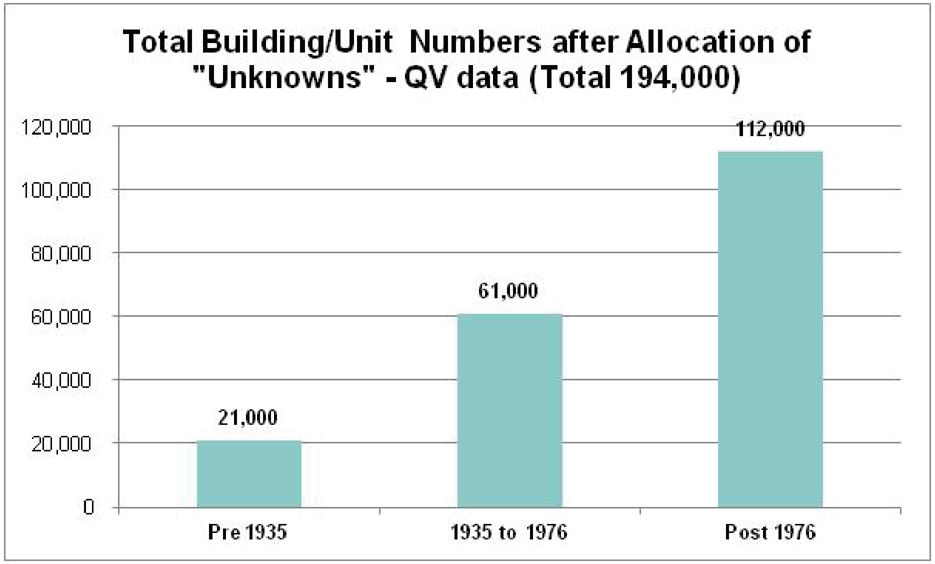
Total building stock

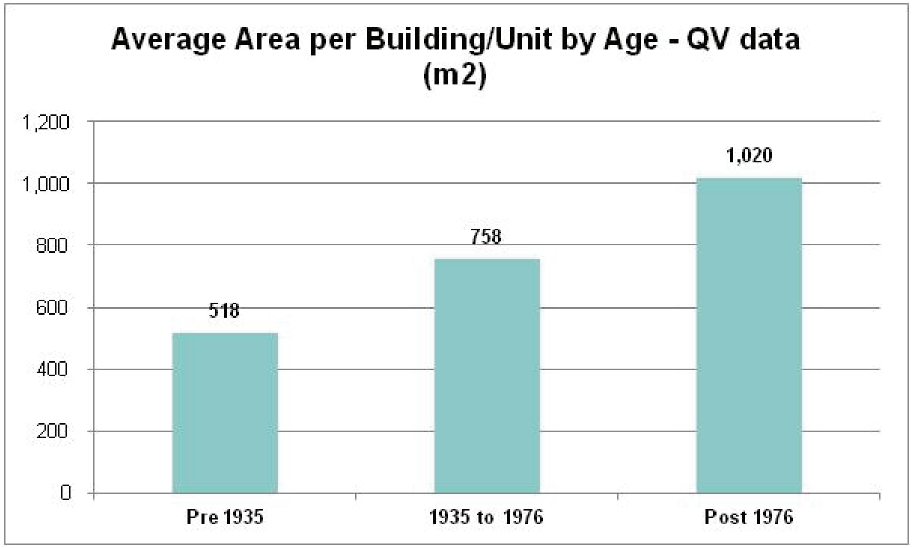


The building stock is relatively concentrated, with 50% of the total building area for New Zealand in the top 7 TAs and 80% in the top 25. (There are 74 TAs in the QV database as it includes seven separate Auckland areas and the Chatham Islands). Total area for all buildings in New Zealand is 171,000,000m2.

Total building stock

- According to the QV database, the total number of buildings/units in New Zealand is 194,000. 11% were built pre 1935 and 31% were built between 1935 and 1976:





- The average area per building/unit is 884m2, but this differs depending on the age of the building. Newer buildings are on average larger than older buildings, with post 1976 buildings being on average almost twice as large as pre 1935 buildings.

Earthquake prone building stock (EPBs)

Existing data on the numbers of EPBs in New Zealand is scarce. Several rough estimates have been made (e.g. Jason Ingham, David Hopkins) but all have recognised the serious lack of data and have caveated their results accordingly.

The estimates for the CBA Model are no different. The work has considered and interpreted the available data, including the previous studies, but at best the numbers are only indicative.

To take account of this uncertainty around the make-up of the building stock the CBA Model applies a robust sensitivity analysis across all the results.

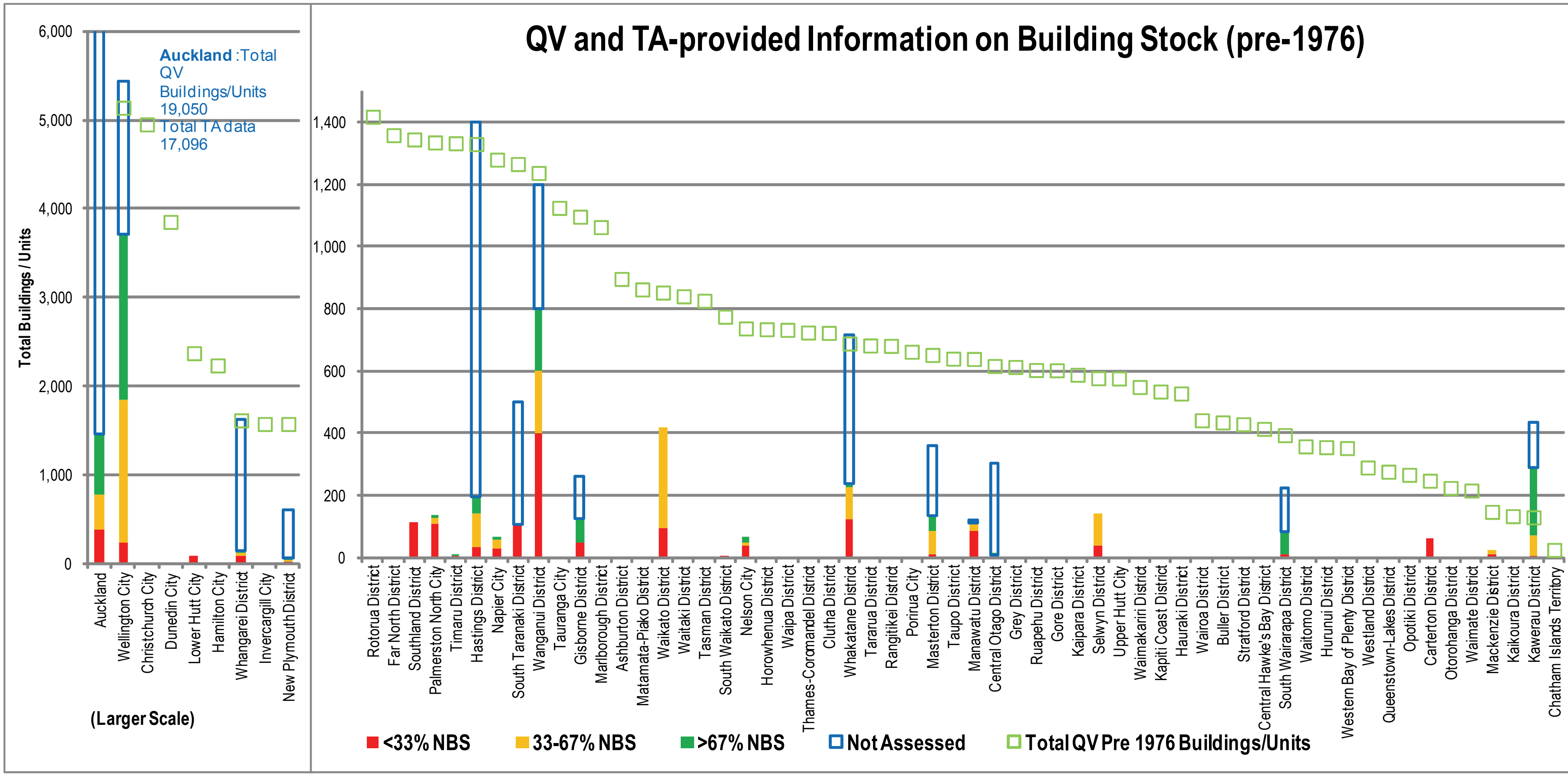
The estimates for EPBs were developed as follows:

- In March 2012, DBH carried out a survey of all TAs across New Zealand asking for details of EPBs (among other things). Unfortunately, this survey provided very little data on EPBs with most councils either just starting to gather data on their EPBs or not yet having started. The exception was Wellington City Council which had made significant progress in identifying the city's at-risk buildings.

- Survey results are shown on the following page:

Earthquake prone building stock (EPBs)

Summary of initial TA survey response. Incomplete data from all TAs with some useful data from Wellington and Whanganui. (The green boxes show the QV volumes. The bar charts for each TA show data provided in the survey. For data for a TA to be useful, the red, orange and green bars should be close to the green box)



Earthquake prone building stock (EPBs)

- Following the poor response from the survey, in July 2012, councils of ten of the major cities and towns in New Zealand were contacted directly by phone and the latest EPB data was requested. Data was obtained between 9 July and 19 July 2012.
- Dunedin and Rotorua had no current data. Christchurch was not approached and Hamilton had a limited amount of data.
- As a result, this approach provided useable data and estimates from seven councils - on buildings <33%NBS as well as on buildings between 33% and 67%NBS. This group of councils were: Auckland, Wellington, Hastings, Nelson, Whangarei, Whanganui, and Whakatane.
- The data collected related only to pre-1976 building stock. This is because it is most likely that buildings <33% NBS will have been built before a building code change in that year – and buildings below 33% have been the focus of the councils to date.

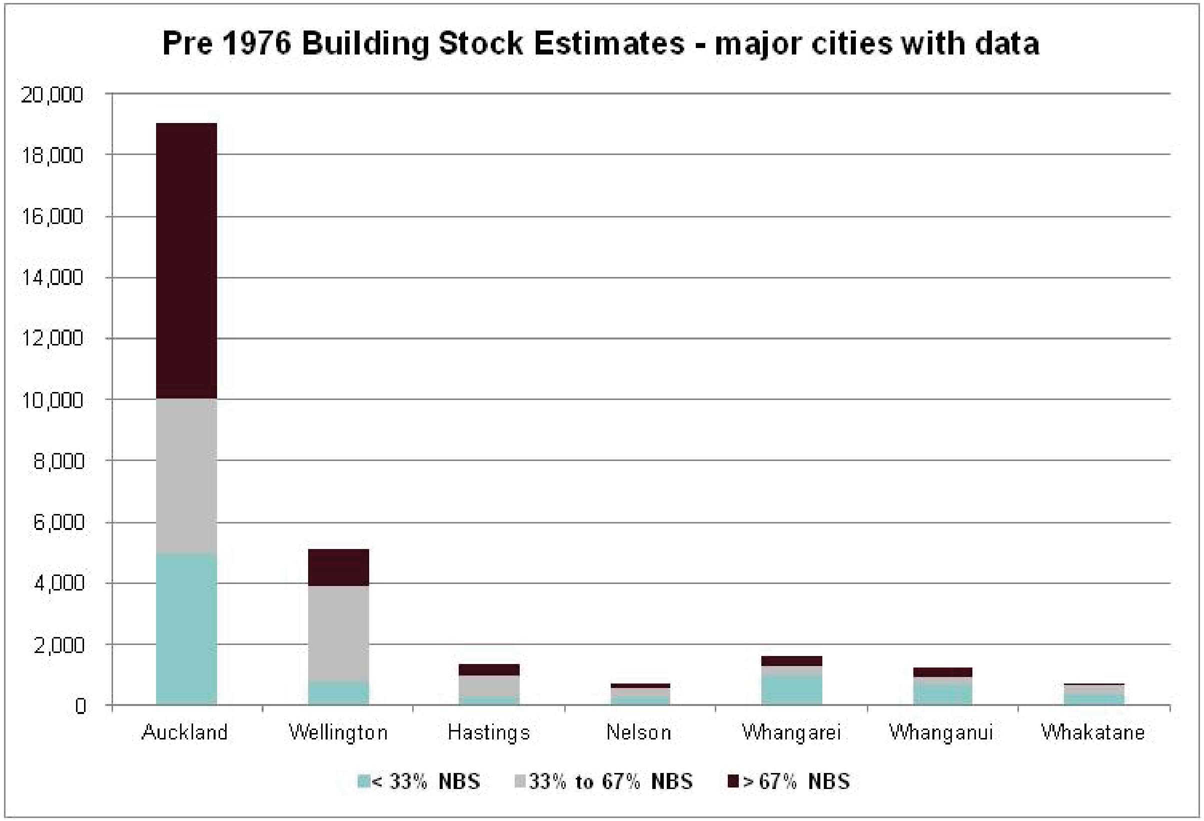
Earthquake prone building stock (EPBs)

- The following table shows the detailed information received from the seven councils listed above.
- The extrapolated data applies the results from the assessments to date to the whole population, or in other cases shown below, estimates for the pre-1976 population were provided by the councils
- More representative data was received from a second source for Wellington and this was used in the calculations.
- The Councils in the table represent 36% of the total number of pre-1976 buildings and overall the Councils have completed, on average, only 22% of their assessment programmes.
- The limited completion of assessments and the risks of extrapolating the data were discussed with each of the Councils. As noted above, even though the results are based on the latest and most complete information that is available – at best they can only be considered as indicative.

Detailed information from major centres, and extrapolation to estimate buildings <33%NBS and between 33% and 67% NBS

	Per Council Data/Estimate										
	Numbers assessed or on register (pre 1976)						Extrapolated to all pre-1976 building stock				
	< 33% NBS	33% to 67%	> 67% NBS	Total Assessed	Pre 1976 QV	% Assessed	< 33% NBS	33% to 67%	> 67% NBS	Total Estimate	
Auckland	380	393	693	**1,465**	19,050	**8%**	4,941	5,104	9,005	**19,050**	
Wellington	239	1,607	1,865	**3,711**	5,139	**72%**	750	3,160	1,229	**5,139**	<< Uses alternative Council data
Hastings	35	108	54	**197**	1,330	**15%**	236	729	365	**1,330**	
Nelson					737		258	332	147	**737**	<< Council estimate (not assessment)
Whangarei	89	27	28	**144**	1,616	**9%**	999	303	314	**1,616**	
Whanganui	450	200	200	**850**	1,237	**69%**	655	291	291	**1,237**	<< Council estimate (not assessment)
Whakatane	124	101	11	**236**	689	**34%**	362	295	32	**689**	
Sub-total	**1,317**	**2,436**	**2,851**	**6,603**	**29,800**	**22%**	**8,202**	**10,214**	**11,384**	**29,800**	
	20%	37%	43%	100%			28%	34%	38%	100%	
All pre 1976 Buildings										81,838	
Percent of pre-1976 in table										**36%**	

Earthquake prone building stock (EPBs)



Earthquake prone building stock (EPBs)

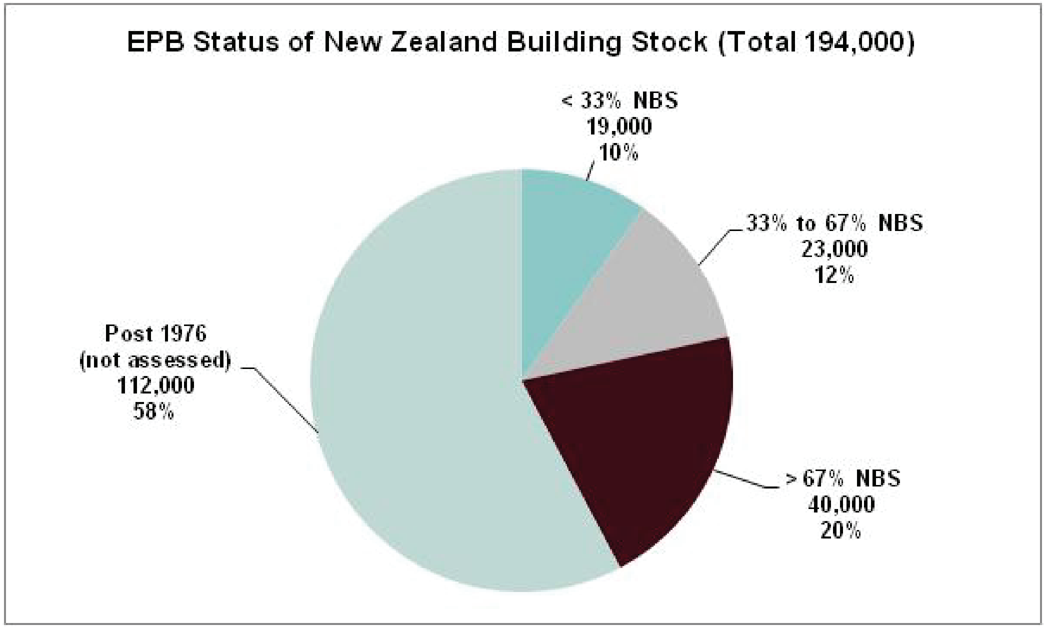
- From this data, the ratio of buildings that are 33-67% NBS compared to the buildings that are <33% NBS is 1.2. (This was based on an average of the TA ratios, excluding Wellington. Wellington was excluded because it appeared to be an outlier compared to the other TA results).
- This ratio is applied to all other TAs to estimate the number of buildings between 33% and 67% NBS, based on the recorded or calculated data for buildings below 33%.

Additional data sources

- In addition to the direct contact made with major councils, an internet search was carried out for any further information about EPBs across New Zealand. This produced additional information on buildings below 33% NBS from Council lists of EPBs, as well as from press reports. (Searches were made by DBH, the Ministry of Culture and Heritage and MartinJenkins).
- Additional data was sourced from 16 TAs: Tauranga, Lower Hutt, Manawatu (Fielding), Palmerston North, Central Otago, Opotiki, Selwyn, Hamilton, SouthTaranaki, Tararua, Masterton, Marlborough, Hurunui, Waimakariri, Clutha, and Westland.
- This data was of low quality, comprising estimates that included either most of the pre-1976 building stock, or were from partially completed assessment programmes.
- The combined data from all the 23 councils with usable information provided the overall indicative estimate of the EPB stock. This data suggested that, across New Zealand, 24% of all pre-1976 buildings could be below 33% NBS.
- In comparison, the average percentage for the seven councils with higher quality data was 28%.
- An indicative estimate of the EPB status of the New Zealand building stock is shown in the chart on the following page
- Note: buildings built after 1976 have not been assessed, but it would be fair to assume that a significant number of such buildings will be between 33% and 67% NBS.

Earthquake prone building stock (EPBs)

- Across New Zealand there are estimated to be about 82,000 pre-1976 buildings/units out of the total building stock of 194,000. This is 42% of the total.
- Buildings below 33% are estimated to be 10% of the total, being 19,000 buildings/units.



Earthquake prone building stock (EPBs)

Summary of point estimates and indicative range of building stock numbers (before applying attrition rates for buildings that would not be strengthened regardless of the policy settings):

EPBs - Building Stock Assumptions

Number of Buildings / Units - Point Estimates			
EPB Status	Age		
	Pre 1976	Post 1976	Total
< 33% NBS	19,000		19,000
34-67% NBS	23,000	0*	23,000
> 68% NBS	40,000	112,000	152,000
Total	**82,000**	**112,000**	**194,000**

* Not assessed

Number of Buildings / Units - Range of Estimates		
EPB Status	Number	Percent of Total
< 33% NBS	15,000 to 25,000	8% to 13%
34-67% NBS	15,000 to 30,000**	8% to 16%
> 68% NBS	135,000 to 160,000	71% to 84%
Approx Total	**190,000**	

** Excluding post 1976 buildings

Numbers for 34-67% NBS (post 1976 buildings) are not included in the results. No actual data or Council estimates are available for this group of buildings, but anecdotal evidence (from MBIE-BH) suggests that up to an additional 50,000 post -1976 buildings could be between 33% and 67% NBS.

Earthquake prone building stock in CBA model

CBA Model - use of building stock

- The building stock used in the CBA model is reduced by an "attrition rate" of 10% for <33% NBS buildings and 5% for 33%-67% NBS buildings to take account of buildings not expected to be strengthened regardless of the future policy.
- These rates are judgement-based, and the lower rate for 33%-67% NBS reflects that these buildings are more likely to be newer (and therefore more likely to be strengthened) than the <33% NBS buildings.
- ***As noted above, the large uncertainty around the actual make-up of the building stock is managed in the CBA Model by applying a robust sensitivity analysis across all the results.***

Strengthening costs for individual buildings

Costs of strengthening buildings

- A range of strengthening costs per m2 of floor area for 33%, 67% and 100% strengthening options was provided by engineers (Adam Thornton and Win Clark; and separately by John Hare).
- The ranges were necessarily large because of the wide nature of the buildings, as well as to account for some regional variation in building costs.
- The table below shows the costs used in the base case of the CBA Model. The table shows the costs of strengthening pre 1935 buildings, and buildings built between 1935 and 1976, to 33%, 67% and 100% NBS.

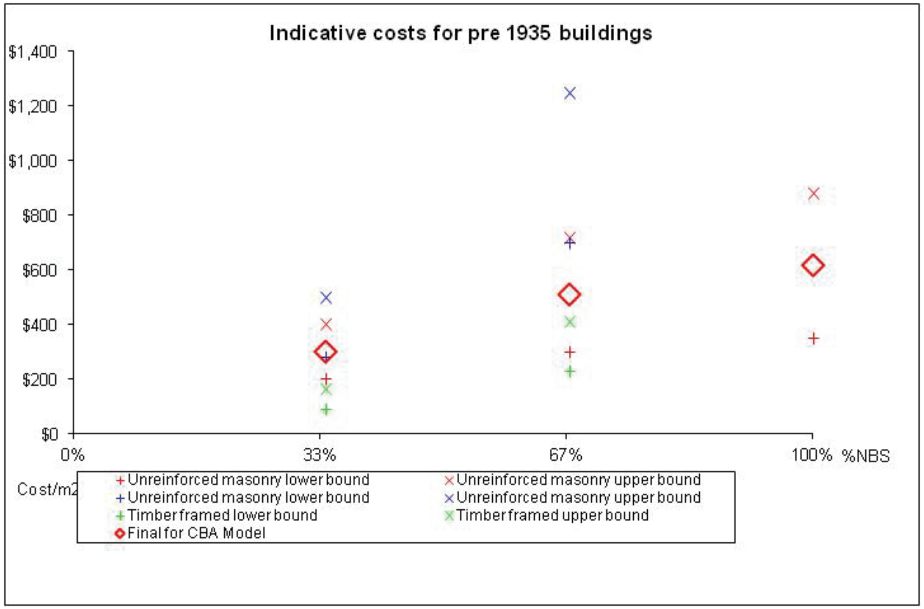
- The charts on the following pages show the available data-sets and the amounts used for the CBA Model base case (as also shown in the preceding table).
- The data selected for the model was based on the mid-points of the Adam Thornton and Win Clark estimates. (The 1935-1976 estimate used the weighted average results of the 1935-65 and 1965-76 data).

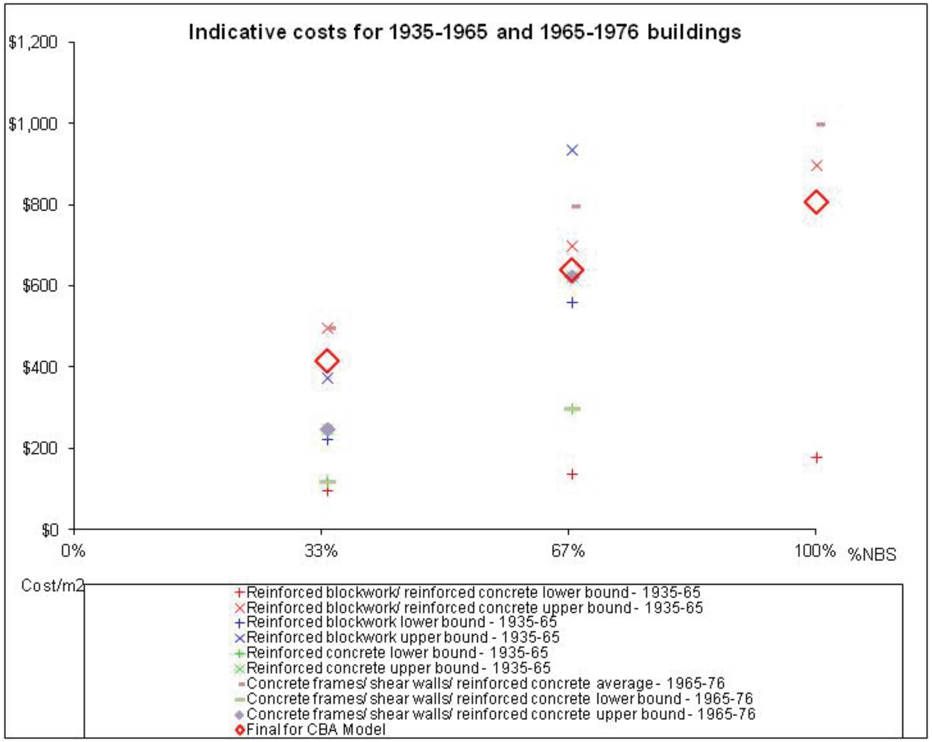
- ***Cost uncertainty was managed in the CBA model by applying a robust sensitivity analysis to the results***

	34%NBS	67%NBS	100%NBS
Pre 1935 buildings	$300	$510	$615
1935 - 1976 buildings	$416	$640	$807

Strengthening costs for individual buildings

Summary of engineers cost estimates and the CBA Model selection:





Costs of strengthening buildings - and timing to complete

Additional costs

- Costs of fire and disabled access upgrades are able to be included in the CBA model, but were set at zero for the base case.

Phasing of strengthening timetable

- The CBA Model includes a phasing of the strengthening timetable that can be set to various distribution shapes including flat, normal and a late skew. The base case uses a late skew, with greater strengthening occurring towards the end of the legislated timeframe, as follows:

Strengthening Cost Methodology

- Cost is a function of total <33% NBS and 33%-67% NBS buildings per TA, less attrition (those not strengthened), times cost/m2 to strengthen (plus additional costs if selected), allocated across the policy timeframe based on a selected distribution type (skewed, normal, linear).

CBA Model

TOTAL COSTS OF STRENGTHENING

Summary of CBA Model Strengthening Costs

Three "base case" options were modelled:

(1)33% strengthening with shortening of the timeframe from the current average period of 28 years to a maximum timeframe of 15 years

(2)67% strengthening with a timeframe of 15 years

(3)100% strengthening with a timeframe of 15 years

As noted earlier, the status quo assumes that the current standard of 33% is implemented according to existing timeframes. This is an average of 28 years.

The three options above are compared to the status quo (current 33% case) to provide an estimate of incremental costs.

The following page summarises the base case modelled results:

Summary of CBA Model Strengthening Costs

(3 strengthening options: (1) 33% with reduced timing; (2) 67%; and (3) 100%

Building Strengthening Costs

Attrition Rate (being percent of stock not strengthened for any reason (including allowing for some already strengthened, and allowing for total replacement where this is economic in all scenarios).

<33% NBS - Attrition Rate	10%
33%-67% NBS - Attrition Rate	5%

Building Stock for Strengthening			
(total stock less Attrition)	Number	Area	Average m2 per building
<33% NBS	17,424	11,994,163	688
33%-67% NBS	22,012	15,617,133	709
Total	**39,435**	**27,611,295**	**700**

Base Strengthening Costs	To 33% NBS	To 67% NBS	Ratio	To 100% NBS	Ratio
<33% NBS	$300/m2	$510/m2	1.70	$615/m2	1.21
33%-67% NBS		$640/m2		$807/m2	1.26

Include Additional Fire/Access Costs?
No

Total Strengthening Costs for 3 options		Total Real $m	NPV $m
<33% to 33% - Current Timing	28 Years	$3,598m	$958m
<33% to 33% - Policy Timing	15 Years	$3,598m	$1,717m
Incremental Cost vs Current 33% Case >		**$0m**	**$760m**
<33% to 67%		$6,117m	$2,919m
33%-67% to 67%		$10,000m	$4,772m
Total Cost to Strengthen to 67%		$16,117m	$7,692m
Incremental Cost vs Current 33% Case >		**$12,519m**	**$6,734m**
<33% to 100%		$7,376m	$3,520m
33-67% to 100%		$12,599m	$6,012m
Total Cost to Strengthen to 100%		$19,975m	$9,533m
Incremental Cost vs Current 33% Case >		**$16,377m**	**$8,575m**

Strengthening Timing Assumptions (used for NPV)	
Maximum Time to Strengthen	
Status Quo (weighted average of TAs)	28 Years
Maximum Years to Improve buildings <33% NBS	15 Years
Maximum Years to Improve buildings 33%-67% NBS	15 Years

CBA Model

BENEFITS

Benefit Inputs and Calculations

Benefit Inputs and Calculations

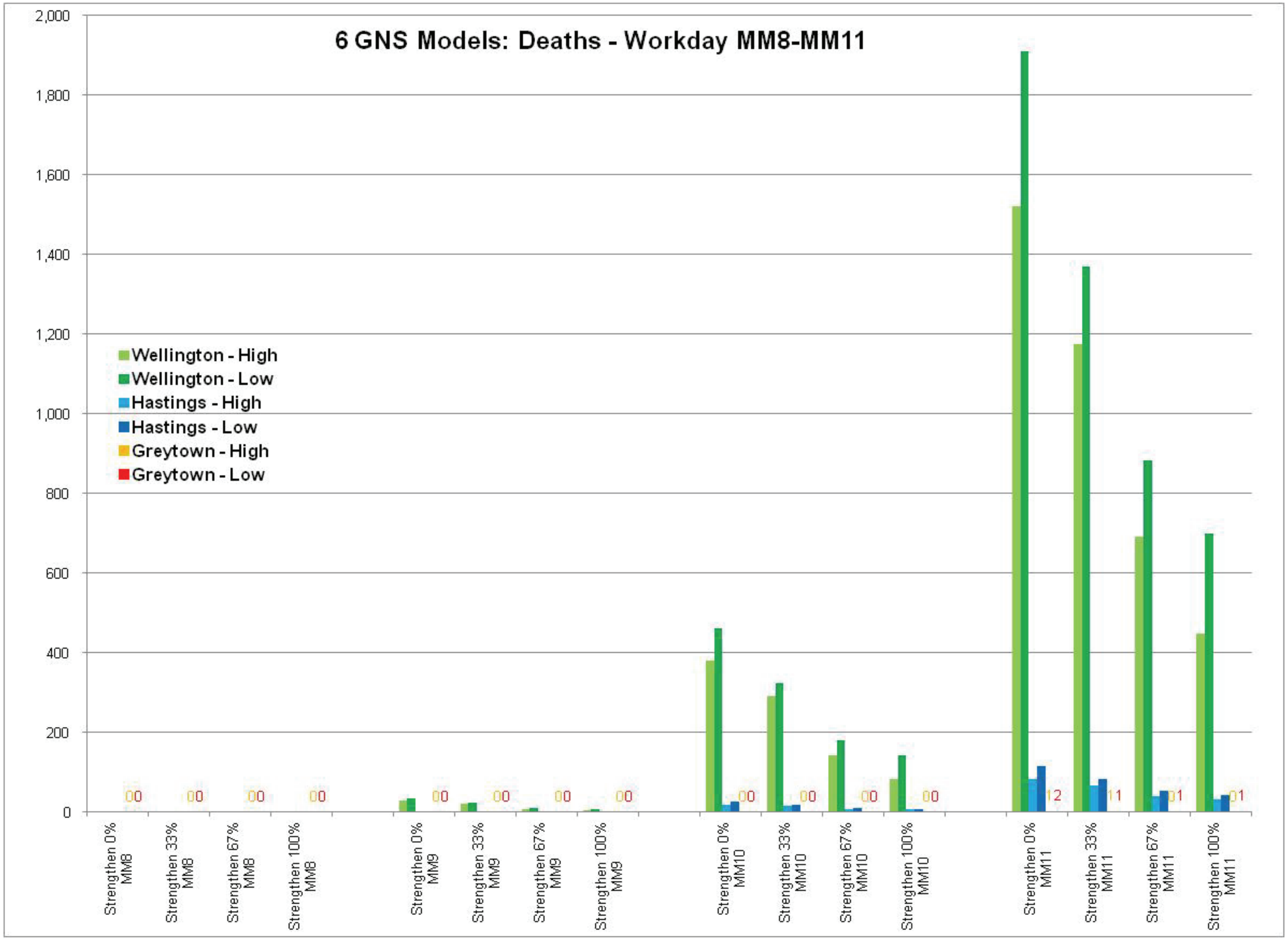
Information on the benefits arising from earthquakes is limited and difficult to estimate. GNS has provided all the base information for the CBA Model and have run a number of specific models to provide the required inputs.

The CBA Model takes the GNS results and extrapolates and modifies these for all the TAs using, where relevant, population, building areas, geography, seismicity or earthquake probabilities.

- Three representative high seismicity cities/towns (Wellington, Hastings, Greytown) were modelled for earthquakes by GNS, producing estimates of expected workday deaths and injuries, non-workday deaths and injuries and damage costs.
- The models also estimated impacts on the public outside of buildings, on the city/town streets.
- These centres were selected by GNS due to the data and models that were available at the time.
- They were also selected as they gave a fair representation of three difference sizes of New Zealand centres: large city, medium centre, small town.
- The three models were expanded by GNS to six models by tweaking the inputs to produce low seismicity equivalents. The models are:
  - Wellington – HIGH Population: 179,000
  - Wellington – LOW
  - Hastings – HIGH Population: 62,000
  - Hastings – LOW
  - Greytown – HIGH Population: 2,000
  - Greytown – LOW
- For example, the LOW seismicity Wellington model is designed to represent the impacts in a city such as Auckland. (Wgtn Z-factor 0.40; Auckland Z-factor 0.13).
- The six GNS model results were scaled and applied to other cities/towns across NZ based on relative populations for major towns and cities in each TA as well as seismicity. An alternative allocation using relative building areas in each TA was also calculated but this did not produce a material difference so the population allocation driver was retained.

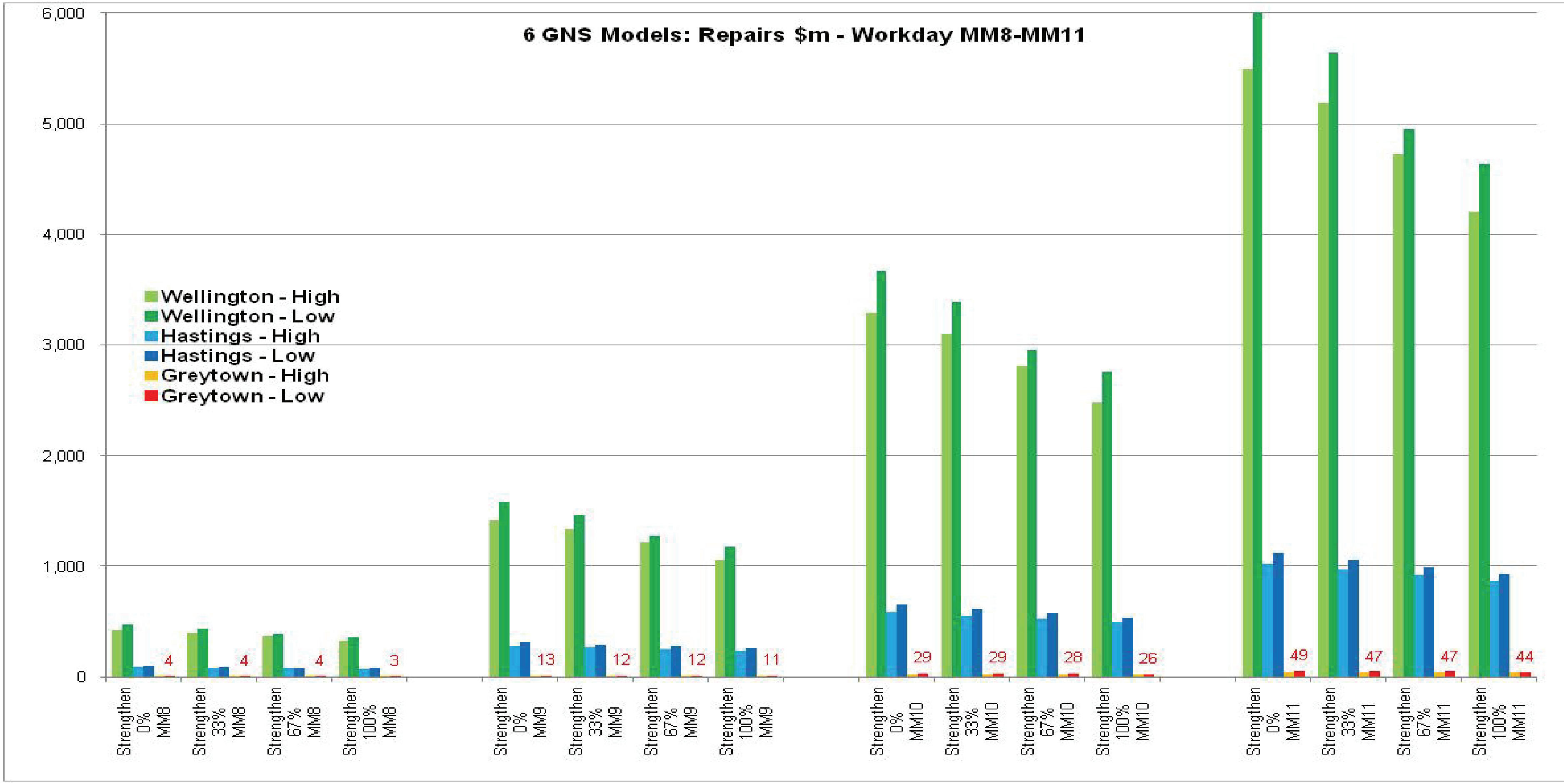
GNS Models Example Output – (Workday deaths MM8 – MM11)

This chart of workday deaths demonstrates the expected low impact of MM8 and MM9 earthquakes and the total scale of a large earthquake. (Note that the three LOW seismicity scenarios have weaker buildings and therefore suffer greater harm than HIGH seismicity scenarios, given the same size of event. E.g. Wgtn Low > Wgtn High).



GNS Models Example Output – Repairs ($m) MM8 – MM11

This chart for Repairs shows a similar effect as the chart showing deaths, except there is some damage experienced in the smaller MM8 and MM9 earthquakes.



Benefit Inputs and Calculations (cont)

Allocation of GNS models to TAs

- The six models were assigned to TAs as follows:
  - Wellington uses Wellington High, Hastings uses Hastings High, Greytown uses Greytown High
  - Z-factors for these centres are 0.40, 0.39 and 0.42 respectively
  - If a Z-factor for a TA is less than 0.20 it uses a LOW model, otherwise it uses a HIGH model
  - If total population of a TA is greater than 75,000 it uses a Wellington model, if average town population in a TA is below 5,000 it uses a Greytown model, otherwise it uses a Hastings model
  - The Z-factor and population steps were varied as part of the sensitivity analysis
- Each of the 6 models provided by GNS included results (number of deaths/injuries in a workday/non-workday and costs of damage) under earthquake strengths from MM8 to MM11*.
- This band was selected because:
  - MM12 earthquakes (the maximum) have a huge impact but are not predicted to occur in New Zealand's towns or cities
  - Earthquakes lower than MM8 have a higher probability of occurrence but are not expected to cause material damage for the purposes of the CBA analysis

- * The MM scale is the Modified Mercalli Index.
  - The size of an earthquake is often described using magnitude, which is the amount of energy released during an earthquake. However, not all of the energy released in an earthquake will necessarily be felt at the surface, depending on the earthquake's depth.
  - In New Zealand, where earthquakes occur from near the surface right down to a depth of over 600 km, the Modified Mercalli intensity scale is a better indicator of an earthquake's effects on people and their environment

The MM scale is described in summary form on the following page:

Background information: Modified Mercalli Intensity Scale

Modified Mercalli Intensity scale:

MM8 to MM11 have been modelled by GNS for the CBA

MM 1: Imperceptible
Barely sensed only by a very few people.

MM 2: Scarcely felt
Felt only by a few people at rest in houses or on upper floors.

MM 3: Weak
Felt indoors as a light vibration. Hanging objects may swing slightly.

MM 4: Light
Generally noticed indoors, but not outside, as a moderate vibration or jolt. Light sleepers may be awakened. Walls may creak, and glassware, crockery, doors or windows rattle.

MM 5: Moderate
Generally felt outside and by almost everyone indoors. Most sleepers are awakened and a few people alarmed. Small objects are shifted or overturned, and pictures knock against the wall. Some glassware and crockery may break, and loosely secured doors may swing open and shut.

MM 6: Strong
Felt by all. People and animals are alarmed, and many run outside. Walking steadily is difficult. Furniture and appliances may move on smooth surfaces, and objects fall from walls and shelves. Glassware and crockery break. Slight non-structural damage to buildings may occur.

MM 7: Damaging
General alarm. People experience difficulty standing. Furniture and appliances are shifted. Substantial damage to fragile or unsecured objects. A few weak buildings are damaged.

MM 8: Heavily damaging
Alarm may approach panic. A few buildings are damaged and some weak buildings are destroyed.

MM 9: Destructive
Some buildings are damaged and many weak buildings are destroyed.

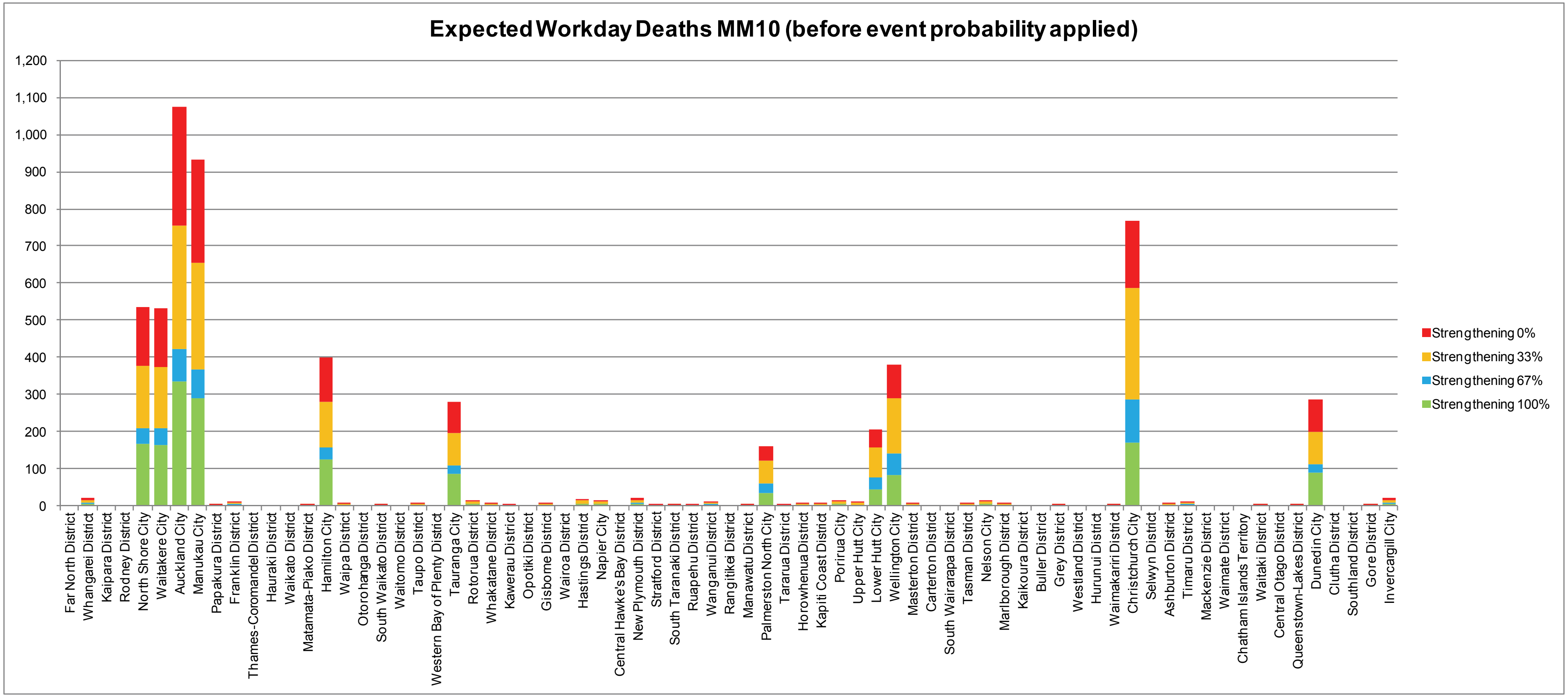
MM 10: Very destructive
Many buildings are damaged and most weak buildings are destroyed.

MM 11: Devastating
Most buildings are damaged and many buildings are destroyed.

MM 12: Completely devastating
All buildings are damaged and most buildings are destroyed.

All TAs - Workday deaths MM10 (MM11 has higher fatalities than MM10, MM9 has fewer and MM8 has nil)

This chart shows example results of applying the 6 models to the TAs for an MM10 event. Significant impacts are only expected in large centres with high populations. Also note: non-workday impacts (not shown below) are approximately 1/10th of workday impacts as fewer people are in the EPBs.



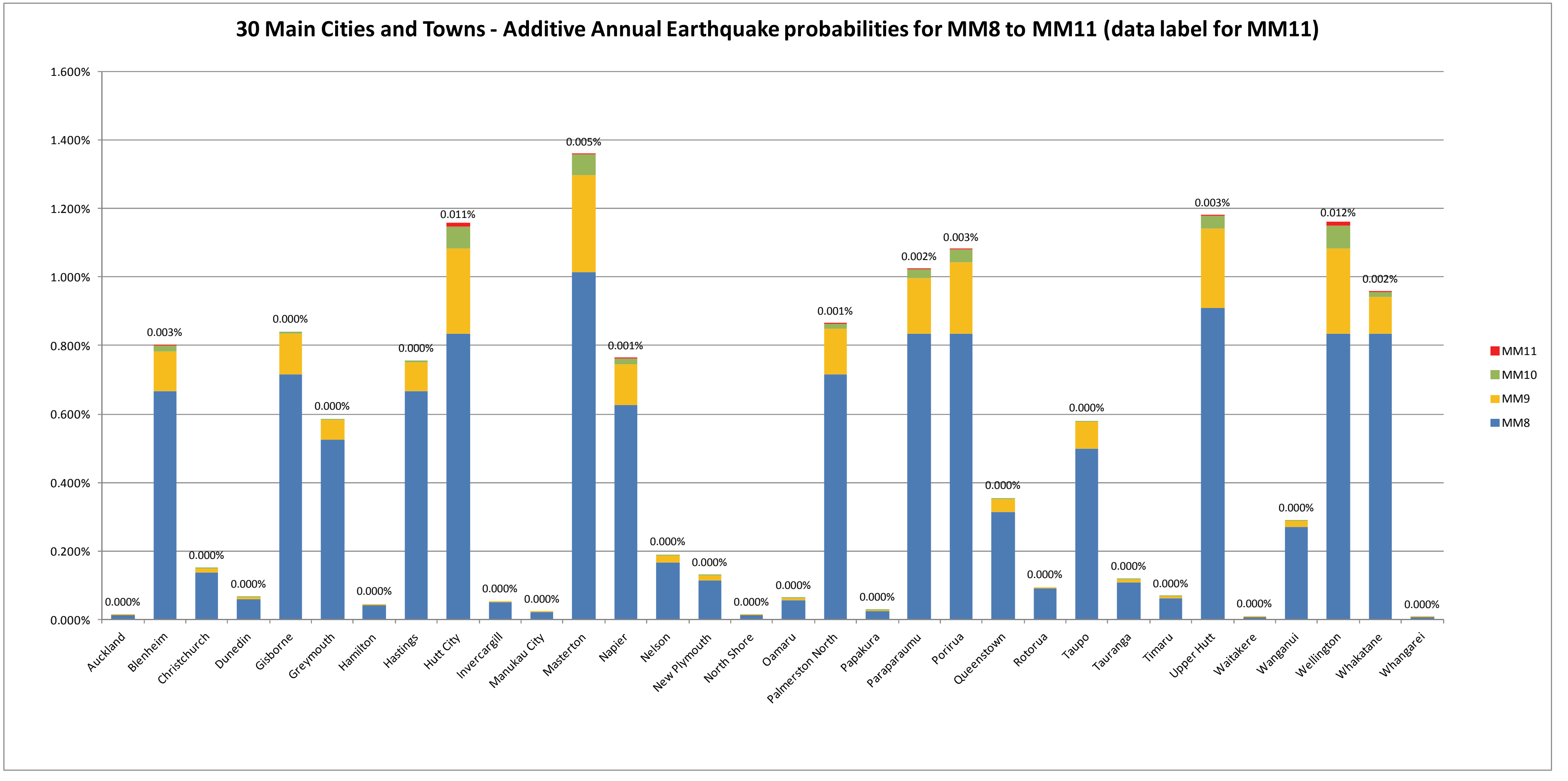
Benefit Inputs and Calculations (cont)

Earthquake probability modelling

- Once a model was assigned to each TA, and scaled up or down according to relative populations, an earthquake probability specific to the TA was applied to each of the MM8 to MM11 results.
- The data for the earthquake probabilities for MM8 to MM11 was provided by GNS. This was for the 30 major towns/cities of New Zealand (and updated earlier work provided for a report by David Hopkins in 2002).
- Data for each of the 30 towns/cities was matched to the relevant TA. For TAs not covered in the list, probabilities were applied to each TA based on the nearest listed data - taking into account both geography & seismicity.
- Where any judgement was required between two options the higher probability factor was applied.
- This is a conservative approach for the CBA Model, reflecting the preliminary results that showed very low benefits compared to costs.
- *This conservative approach was adopted throughout the analysis in order to provide greater comfort over the calculations - and greater confidence around the relationship between estimated costs and estimated benefits.*
- For each TA, the CBA model sums all the impacts of the major earthquakes (MM8-MM11) taking into account their respective probabilities. This produces average annual workday and non-workday deaths/injuries and average damage per TA for all major earthquakes.
- The probability based results of the earthquake modelling are combined into a total probability factor for each TA, together with outputs for weighted average workday and non-workday deaths/injuries and average costs of damage. These are used as inputs into the main part of the CBA Model .

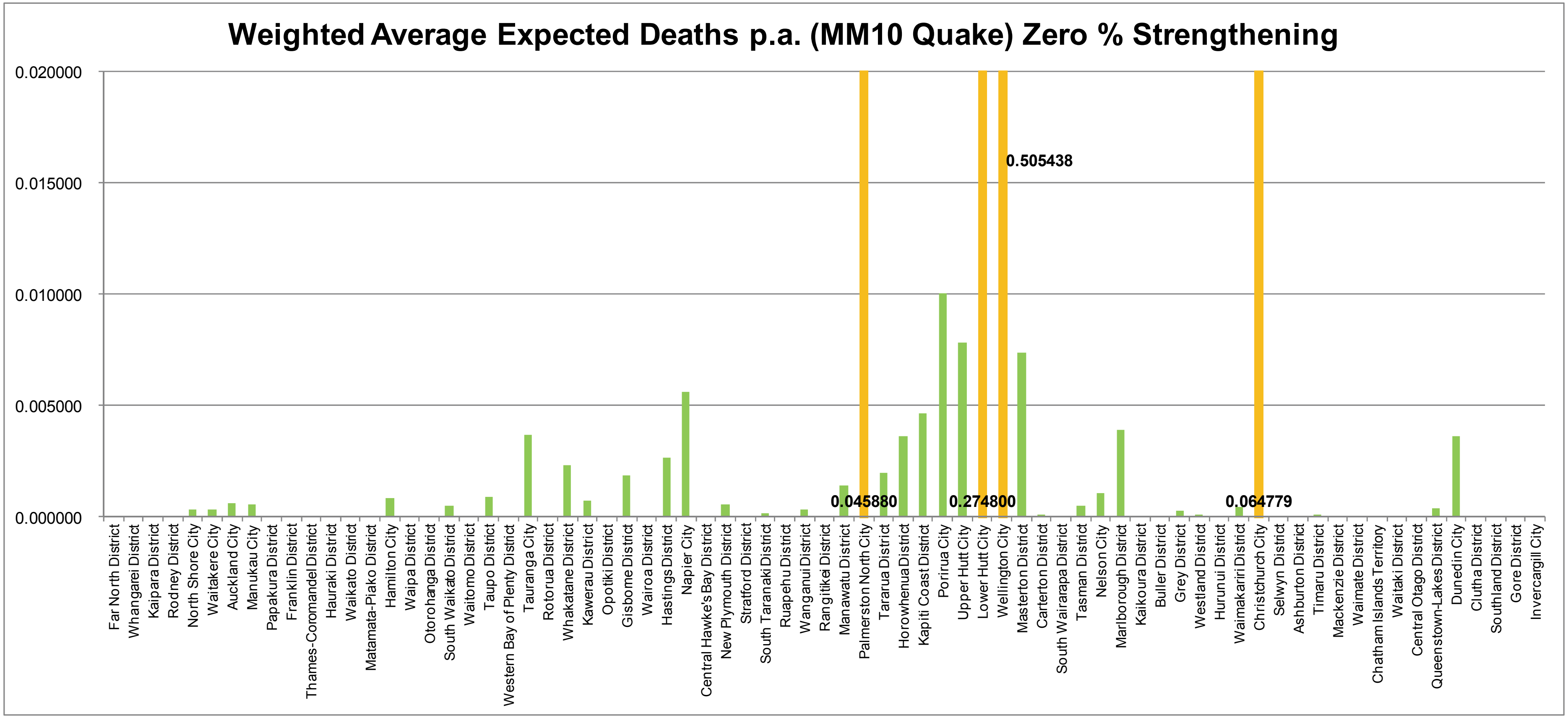
Probability percentages for 30 main towns and cities across NZ

In summary, the GNS percentages show very few areas are expected to have earthquakes of strength MM10 or MM11. While there is a much higher probability of an MM8 earthquake across the country, an event of that size is not expected to cause any deaths and only a small amount of damage. (Probabilities are shown as additive for presentation purposes).



Expected deaths after applying probability – annual average by TA (orange = off the scale)

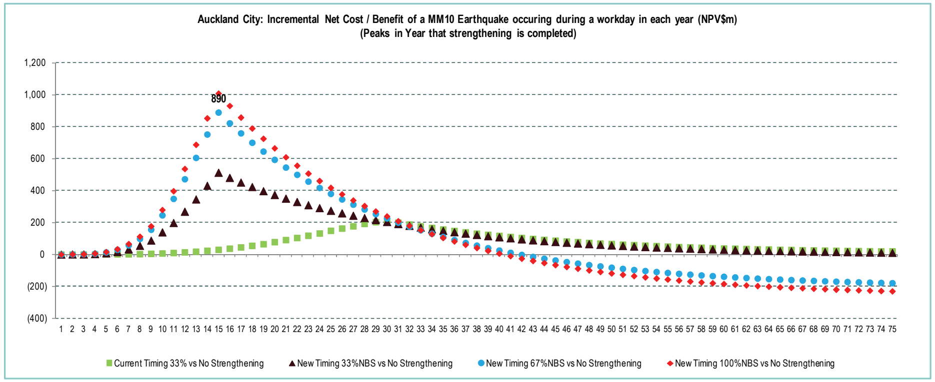
Once probabilities are applied to the total number of deaths that could be caused by an earthquake event, the expected deaths are very small in all TAs except Palmerston Nth, Lower Hutt, Wellington and Christchurch. The Auckland cities all have very low probability of earthquakes, giving low expected deaths in spite of high populations.



Benefits – CBA model calculations

Benefit Calculations in the CBA Model

- The data provided by the GNS models and probability calculations (as described in the previous section) results in annualised estimates of deaths, injuries and damage in the event that an earthquake occurs in each of the TAs across New Zealand.
- These results are applied in the CBA model as follows:
  - In the first year of the CBA model, almost no strengthening has been completed . Therefore, the impact if there was an earthquake would be equal to the impact measured in the GNS work for a “no strengthening” scenario.
  - Once strengthening is completed (at the end of the maximum allowed time under the prescribed policy) the annual benefits will be equal to those measured in the relevant policy option provided by the GNS models.
  - Over the interim period, as strengthening gradually moves from zero to fully completed, the benefits increase from zero to the full amount of the benefit - in proportion to the cumulative amount of strengthening completed at the end of each year.
- Once strengthening is completed the benefits remain flat, in real terms, for the rest of the model.
- As the CBA model measures the Net Present Value of costs and benefits over the term of the model (75 years) the benefits are discounted to current day using the real discount rate. The impact of benefits in outer years is therefore less than the impact of the same benefits were they to occur in nearer years.
- The highest benefits therefore occur in the year that strengthening is completed and they then decline over time until the conclusion of the model.
- The following schematic of a single TA shows the peaks of policy options for 33%, 67% and 100% NBS at 15 Years timing. Current timing of 30 years is also shown in green (this chart is shown in more detail later in this report).



Summary of CBA Model Benefits Data

The following page shows example data from the CBA model for deaths and building collapses for 4 cities (Wellington, Christchurch, Auckland and Hastings).

- This data illustrates the impact of the probability assumptions on the estimated results. For example, although a large earthquake would have a very large impact in Auckland, the probability of this occurring is considered by GNS to be nil (or too low to measure for the purposes of modelling the benefits).
- The base case probability results produced expected annual deaths for New Zealand in a no strengthening case of approximately 1 per annum.
- This appeared low in comparison to historical deaths over the last 169 years which were an average of 3 per annum.
    - Since 1929 the average has been 6 per annum (including Canterbury) and an approximate "population adjusted" estimate of the annual figure is 8.5 per annum.
- A "stretch case" sensitivity has been run which replaces the GNS probabilities for each TA with the highest evidenced probability factor for each earthquake size.
    - On this basis, the expected annual deaths are approximately 8 per annum
    - However, while this case significantly increases the impact of earthquakes and the level of benefits, the benefits still remain considerably less than the costs, particularly for the 67% and 100% strengthening options.

As with other assumptions, uncertainty in benefit calculations was managed by applying a robust sensitivity analysis to the results

Benefits modelling - Example results

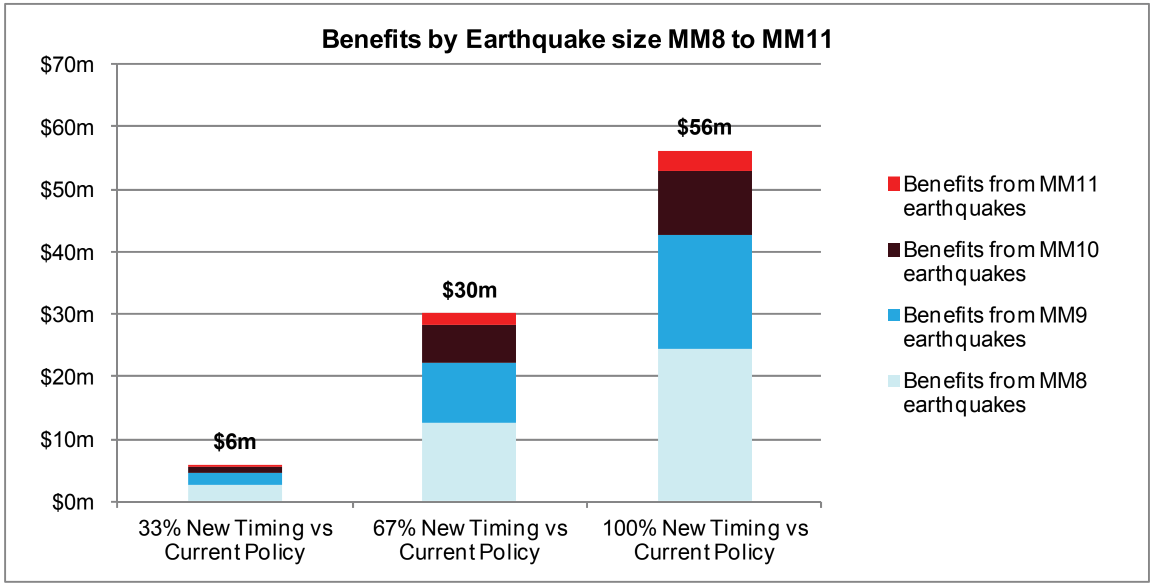
	Estimated Deaths - daytime work-day				Earthquake Return Period (Years)	Estimated Building Collapses			
	No Strengthen	33% NBS	67% NBS	100% NBS		No Strengthen	33% NBS	67% NBS	100% NBS
Wellington									
MM8	0	0	0	0	120	0	0	0	0
MM9	29	20	8	5	400	5	4	2	1
MM10	380	290	142	84	1,500	41	31	17	10
MM11	1,521	1,175	692	448	8,500	204	151	83	48
Expected Annual Impact	**0.50477**	**0.38157**	**0.19608**	**0.12121**		**0.06383**	**0.04843**	**0.02610**	**0.01481**
Christchurch									
MM8	0	0	0	0	720	0	0	0	0
MM9	59	40	16	10	8,900	10	8	4	2
MM10	767	586	287	170	110,000	83	63	34	20
MM11	3,071	2,372	1,397	905	0	412	305	168	97
Expected Annual Impact	**0.01355**	**0.00986**	**0.00442**	**0.00268**		**0.00189**	**0.00148**	**0.00077**	**0.00041**
Auckland City									
MM8	0	0	0	0	7,400	0	0	0	0
MM9	80	51	23	16	120,000	12	9	5	5
MM10	1,076	755	423	334	0	112	84	42	33
MM11	4,467	3,204	2,063	1,633	0	575	414	210	159
Expected Annual Impact	**0.00066**	**0.00043**	**0.00019**	**0.00014**		**0.00010**	**0.00008**	**0.00004**	**0.00004**
Hastings									
MM8	0	0	0	0	150	0	0	0	0
MM9	2	1	0	0	1,200	2	1	1	0
MM10	18	14	7	6	18,000	13	11	6	5
MM11	83	67	40	31	0	62	51	34	26
Expected Annual Impact	**0.00267**	**0.00161**	**0.00039**	**0.00033**		**0.00239**	**0.00144**	**0.00117**	**0.00028**
Total New Zealand (p.a.)	**0.96**	**0.72**	**0.36**	**0.22**		**0.17**	**0.13**	**0.07**	**0.04**
Sensitivity analysis results - maximum probability (return periods for MM8 to MM11 for all cities of 99, 350, 1499 and 8475)									
Total New Zealand (p.a.)	**8.07**	**5.76**	**3.21**	**2.36**		**1.37**	**1.05**	**0.60**	**0.44**

Benefits modelling – results assuming 15 year strengthening timetable

Total benefits for New Zealand and contribution from each earthquake band for MM8 to MM11

	33% New Timing vs Current Policy	67% New Timing vs Current Policy	100% New Timing vs Current Policy
Benefits from MM8 earthquakes	$3m	$13m	$25m
Benefits from MM9 earthquakes	$2m	$9m	$18m
Benefits from MM10 earthquakes	$1m	$6m	$10m
Benefits from MM11 earthquakes	$0m	$2m	$3m
Total Benefits all earthquakes	**$6m**	**$30m**	**$56m**

Much greater benefits are realised from lower intensity earthquakes because, even though they cause less damage and deaths, they have a much higher probability of occurring.



CBA Model

COST / BENEFIT RESULTS

Cost / Benefit Calculations in the CBA Model

Calculation of net cost/benefit results in the CBA Model

- The final step in the CBA model calculations is to combine the annual costs and benefits and to calculate the Net Present Value of the expected results for the 75 years of the model.
- The following table sets out the total costs and benefits for the base case, assuming a 15 year maximum timeframe for strengthening. It also shows net costs and benefits assuming 10 year and 5 year maximums.

CBA Results – high costs, low benefits

(Indicative results – based on the assumptions described in this report)

Indicative Cost / Benefit under 3 new timing options (15, 10 and 5 years)	**COST**	**BENEFIT**	**NET**	**NET**	Increase		**COST**	**BENEFIT**
- Mid point estimate based on extrapolated Council data	NPV $m	NPV $m	NPV $m	$m Cumulative	on Prior		**Cumulative**	**Cumulative**
Cost/benefit to achieve 33% NBS at current timeframes (average 28 years)	$958m	$25m	($932m)	($932m)			$958m	$25m
Additional cost/benefit to achieve 33% NBS in 15 years	$760m	$11m	($748m)	($1,680m)	**80%**		$1,717m	$37m
Plus additional cost/benefit to achieve 67% NBS in 15 years	$5,974m	$52m	($5,922m)	($7,603m)	**352%**	<See below>	$7,692m	$89m
Plus additional cost/benefit to achieve 100% NBS in 15 years	$1,841m	$56m	($1,785m)	($9,388m)	**23%**		$9,533m	$144m
	NPV $m	NPV $m	NPV $m	$m Cumulative			**Cumulative**	**Cumulative**
Cost/benefit to achieve 33% NBS at current timeframes (average 28 years)	$958m	$25m	($932m)	($932m)			$958m	$25m
Additional cost/benefit to achieve 33% NBS in 10 years	$1,237m	$22m	($1,215m)	($2,147m)	**130%**		$2,194m	$47m
Plus additional cost/benefit to achieve 67% NBS in 10 years	$7,635m	$67m	($7,568m)	($9,716m)	**352%**		$9,829m	$114m
Plus additional cost/benefit to achieve 100% NBS in 10 years	$2,353m	$71m	($2,281m)	($11,997m)	**23%**		$12,182m	$185m
	NPV $m	NPV $m	NPV $m	$m Cumulative			**Cumulative**	**Cumulative**
Cost/benefit to achieve 33% NBS at current timeframes (average 28 years)	$958m	$25m	($932m)	($932m)			$958m	$25m
Additional cost/benefit to achieve 33% NBS in 5 years	$1,840m	$35m	($1,805m)	($2,738m)	**194%**		$2,798m	$60m
Plus additional cost/benefit to achieve 67% NBS in 5 years	$9,735m	$85m	($9,649m)	($12,387m)	**352%**		$12,533m	$145m
Plus additional cost/benefit to achieve 100% NBS in 5 years	$3,000m	$91m	($2,908m)	($15,296m)	**23%**		$15,532m	$237m

Explanation of Cumulative Cost Increases (15 year case)		**NPV Costs**	After Attrition Numbers	Ratios			After Attrition Area	Building Avg Size m2	**Nominal Cost**
Base costs to strengthen to 33% over average 28 years		$958m	17,424				11,994,163	688	$3,598m
Additional timing impact of strengthening more quickly		$760m	17,424				11,994,163		$0m
Total Cost of strengthening to 33% over 15 years	a	$1,717m	17,424				11,994,163		$3,598m
Additional costs to strengthen <33% buildings to 67%		$1,202m	17,424				11,994,163		$2,519m
Total cost to strengthen <33% buildings to 67%	b	$2,919m	17,424	b / a	1.70	*Note 1*	11,994,163		$6,117m
Additional costs to strengthen 33%-67% buildings to 67%	c	$4,772m	22,012	c / b	1.63	*Note 2*	15,617,133	709	$10,000m
Total Cost to strengthen both <33% and 33%-67% to 67%		**$7,692m**	**39,435**						**$16,117m**

Note1: This ratio reflects the relative costs of strengthening:

To 33%	$300/m2
To 67%	$510/m2
Ratio:	**1.70**

Note 2: This ratio reflects the greater number of buildings and the higher cost per m2 to repair 33%-67% compared to <33%.

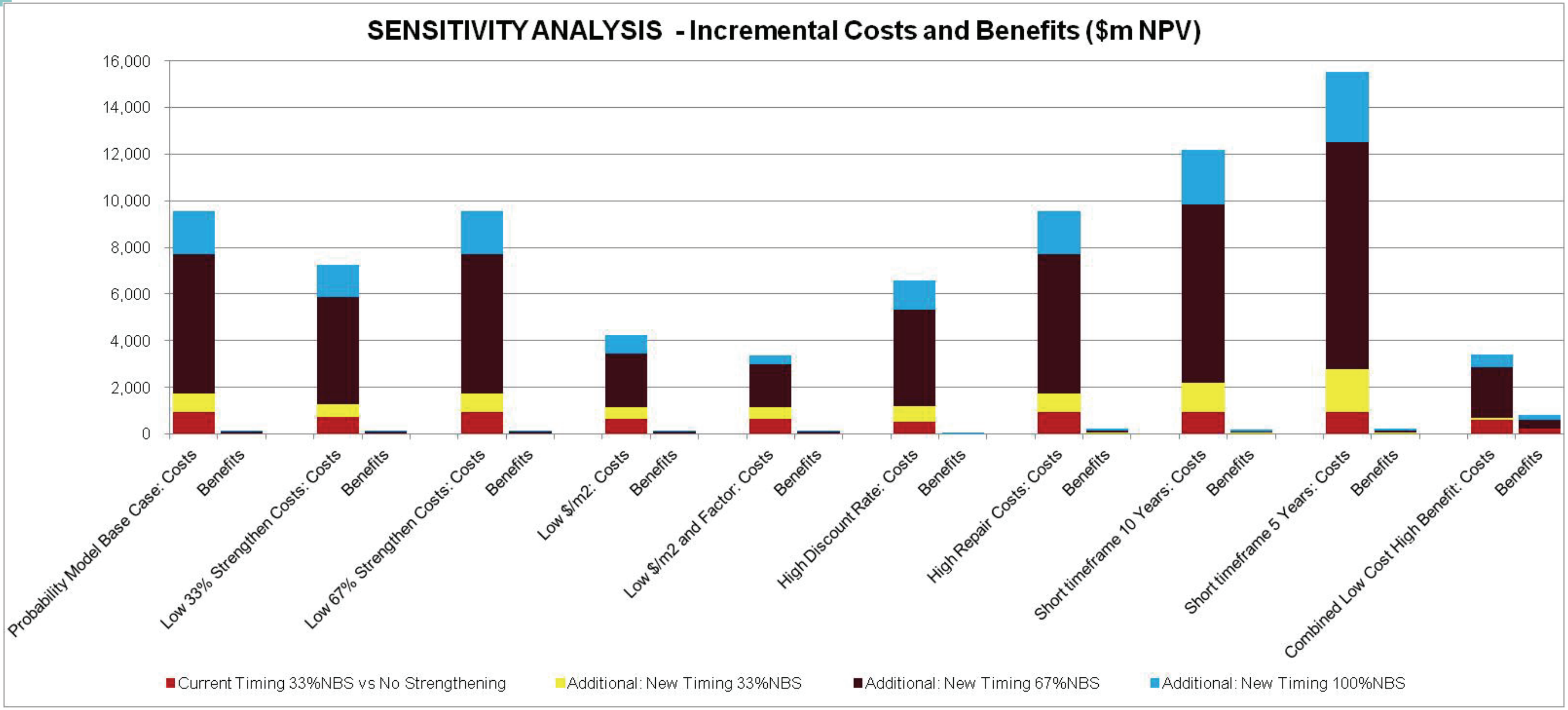
Ratio 33%-67% numbers to <33% numbers	1.30	(Being 15,617,133 / 11,994,163)
Ratio 33%-67% Cost to <33% Cost	1.26	(Being $640/m2 / $510/m2)
Total Ratio	**1.63**	

CBA Results – high costs, low benefits

- Moving to the 67% option is the largest step with the highest net cost. This is mainly due to the greater volume of buildings that are included in a move to 67% compared to 33%. A move to 67% would be expected to require strengthening of a large number of buildings built between 1936 and 1976, whereas a 33% policy mostly includes buildings built before 1936.
- If a new policy is based on shorter strengthening timeframes than those currently in place, this is likely to result in the additional costs being greater than the additional benefits. This is unfavourable from CBA perspective, but may be desired for other reasons.
- Benefit/cost ratios of the options are as follows. All are unfavourable and greater strengthening and shorter timeframes have lower BCRs:

Benefit / cost ratios	
BCR to achieve 33% NBS at current timeframes (average 28 years)	**0.02651**
BCR to achieve 33% NBS in 15 years	**0.02140**
BCR to achieve 67% NBS in 15 years	**0.01153**
BCR to achieve 100% NBS in 15 years	**0.01515**
BCR to achieve 33% NBS in 10 years	**0.02148**
BCR to achieve 67% NBS in 10 years	**0.01157**
BCR to achieve 100% NBS in 10 years	**0.01521**
BCR to achieve 33% NBS in 5 years	**0.02155**
BCR to achieve 67% NBS in 5 years	**0.01161**
BCR to achieve 100% NBS in 5 years	**0.01525**

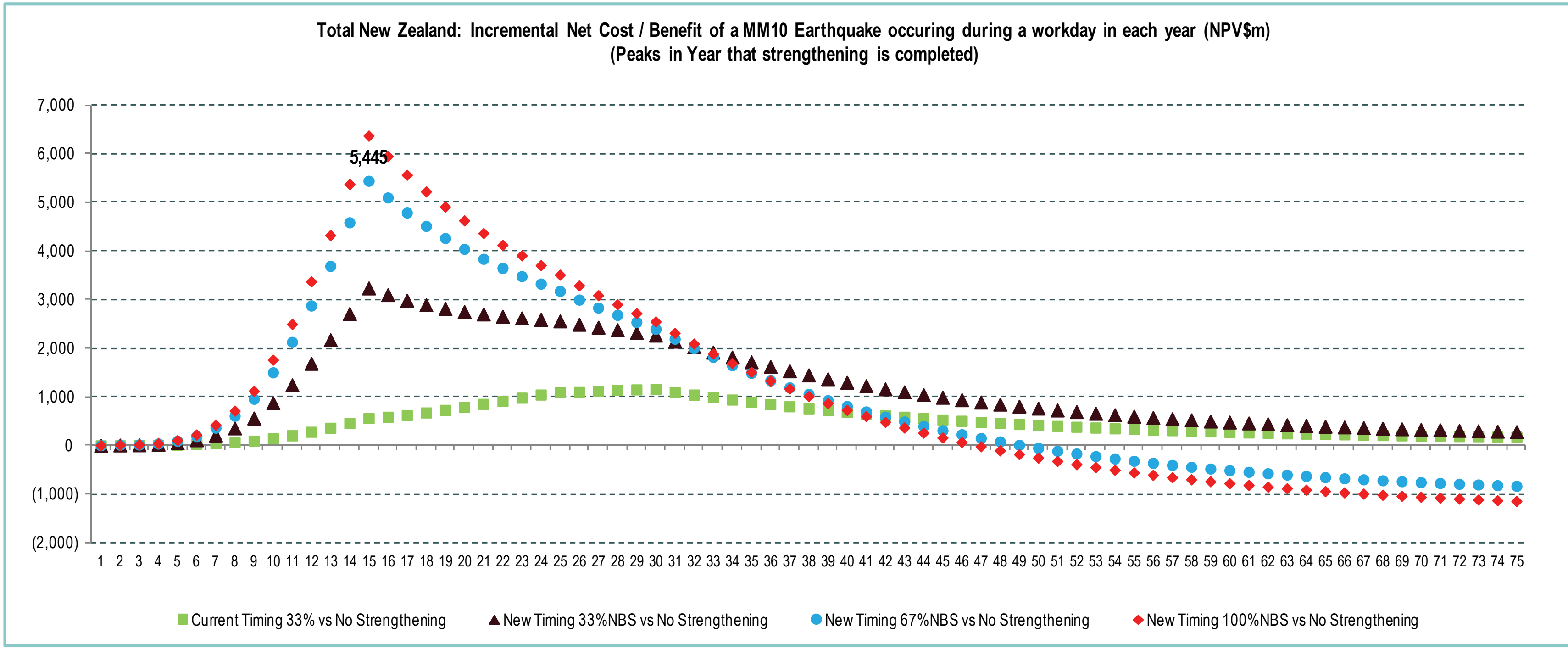
Sensitivities – no material changes to “high cost low benefit” conclusions



- As noted earlier, GNS base probability data only generates average deaths p.a. of 1.0. (This forms part of all the benefits blocks in the chart except the final block).
- A modified sensitivity produces 8.5 deaths p.a. and total benefits on this basis are shown in the last block on the chart . This sensitivity (for benefits) is more in line with actual historical deaths, adjusted for population growth.
- In all cases, even with extreme sensitivity scenarios, costs substantially exceed benefits. This is mainly because large earthquakes that cause significant damage are very rare, and smaller more common earthquakes don’t cause very much damage.

Alternative "actual event" results – Not based on probabilities

This chart shows the combined total impact of separate actual events occurring in each year for all TAs in New Zealand. The results are for an indicative scenario - an MM10 earthquake on a Workday.



- Net benefits peak in the year strengthening is completed (policy set at 15 yrs above, existing average is 28 years)
- 67% and 100% NBS options are positive only between years 5 and 47
- The 33% "new timing" case is more favourable than the 67% or 100% cases after year 32
- The shape of these curves differs across TAs. However, the underlying principle is that that where net benefits are positive, there is a relatively short window of time where this is the case. The effect of discounting decreases the value of future benefits in comparison to the costs (which are incurred up front).

Conclusions of CBA modelling

There are significant data limitations ...

- The TAs currently have very poor records of both their total building stock and in particular the number of earthquake prone or earthquake risk buildings.
- Based on survey returns, Wellington City is the only TA where reasonable data on %NBS of buildings has been collected to date. However, even in Wellington the process is only partially completed.
- The costs of strengthening buildings is difficult to estimate on a general “all of New Zealand” basis. This is because of the wide range of building types that need to be strengthened and the limited amount of data that is publically available on costs of completed work.
- There is currently no New Zealand-wide model that measures the impact of earthquakes, although GNS is in the process of expanding RiskScape . The CBA model has had to be constructed using available data from the limited modelling work already undertaken by GNS.

... But calculations are possible - and sensitivity analysis provides comfort around conclusions

- On a probability basis, costs are well in excess of benefits
- Even under extreme sensitivities, this relationship does not change
- On an actual event basis, there is only a small time window where higher strengthening options show net benefits. This window will shrink and may disappear if higher assumptions were used for building stock numbers.
- The CBA alone does not support higher levels of strengthening - or shorter timeframes.

The CBA model base case has been developed on a conservative basis to provide increased robustness over the model outputs and greater comfort over the conclusions above.