Comparative Risk Assessment for Earthquakes and Other Hazards

Institute of
GEOLOGICAL
& NUCLEAR
SCIENCES
Limited

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Two Aspects of Risk Management

Assessment

Decision making

Earthquake Loss Modelling

A Synthesis of Knowledge

1. What earthquakes are likely to occur?

2. How strong will the shaking be?

3. What will be the effects?

Combine these to get loss probabilities

Where? How big? How often?

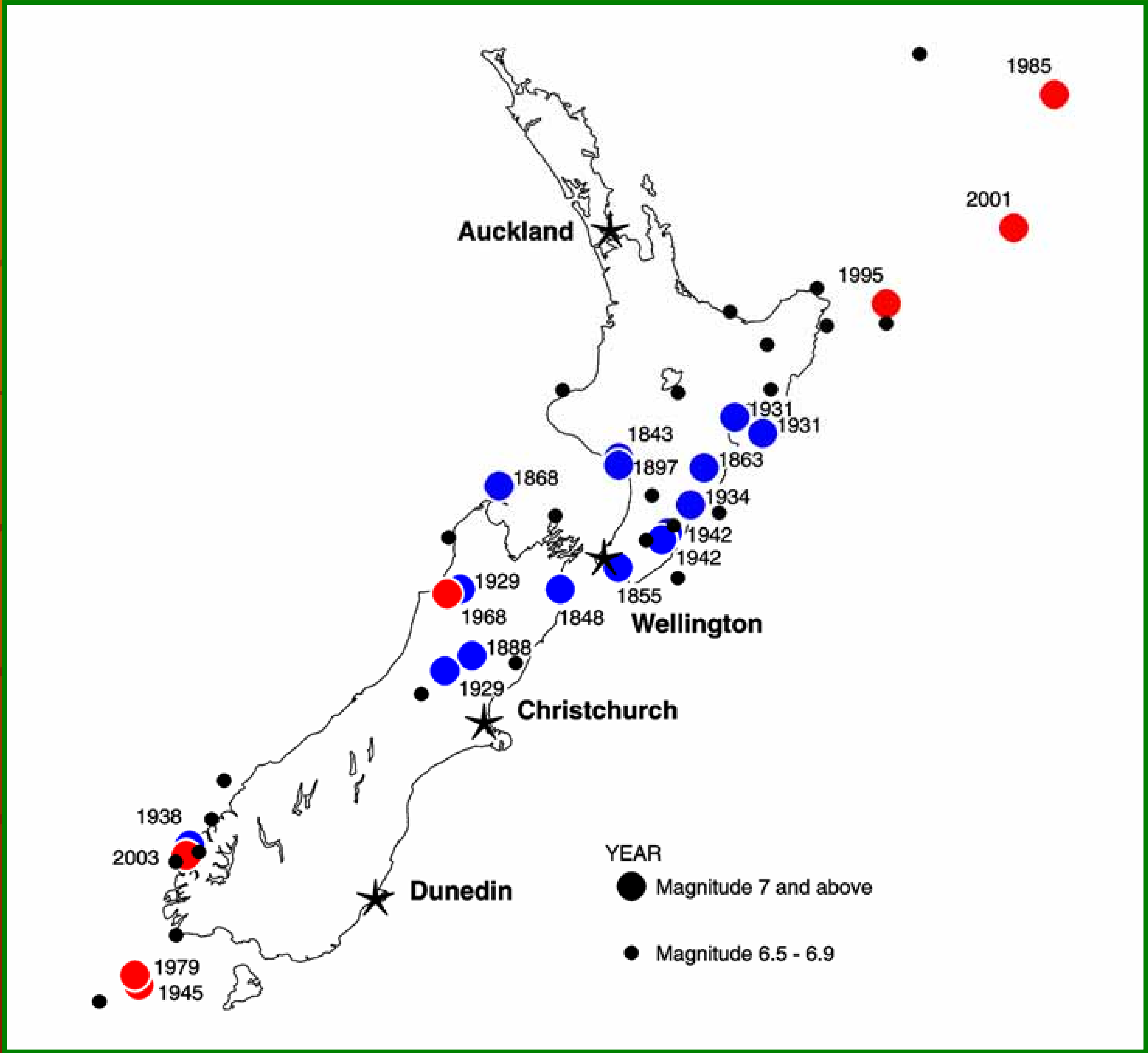
Input: Historical large earthquakes

Small recorded earthquakes

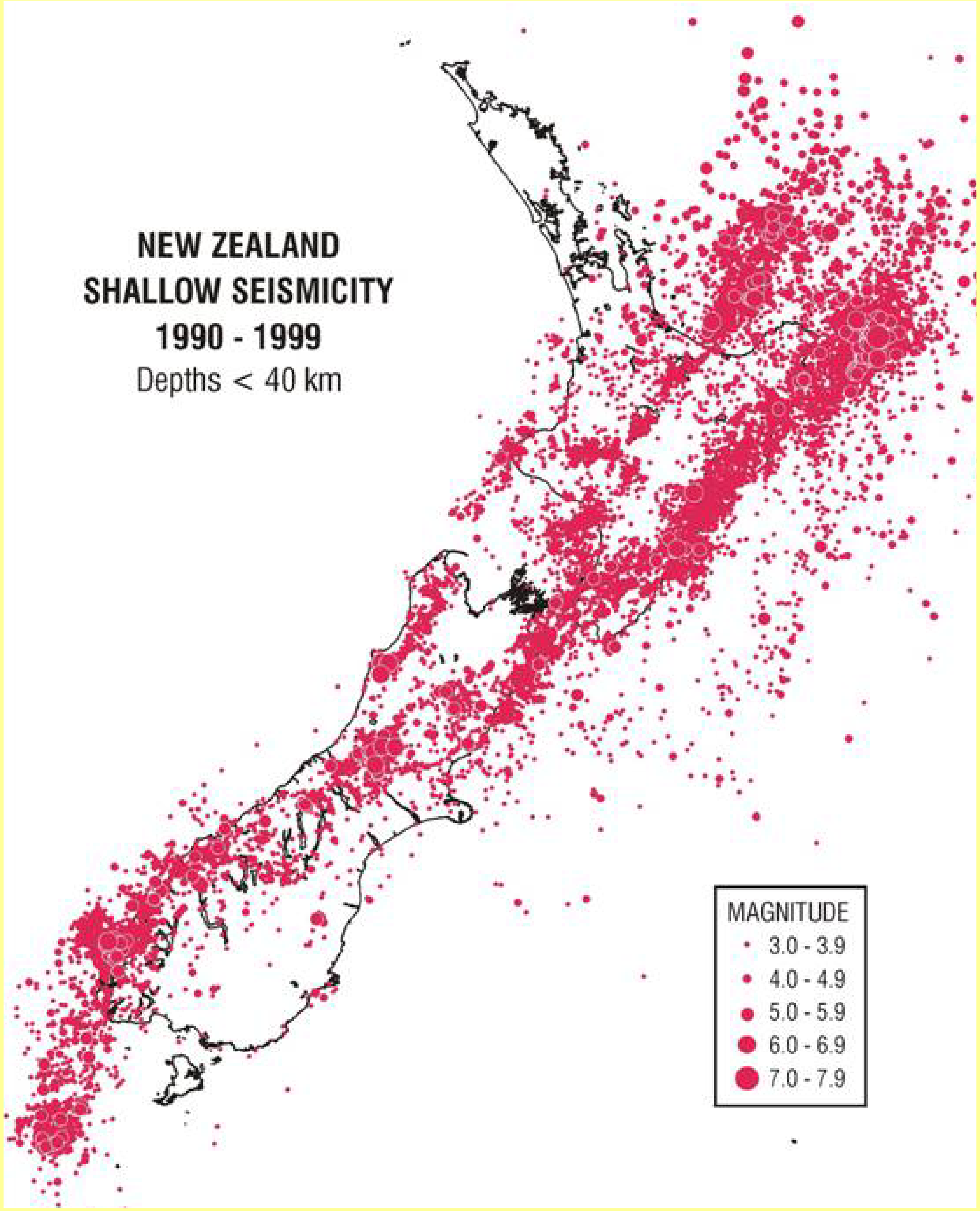
Geological investigations

Output: Fault model

Background seismicity model

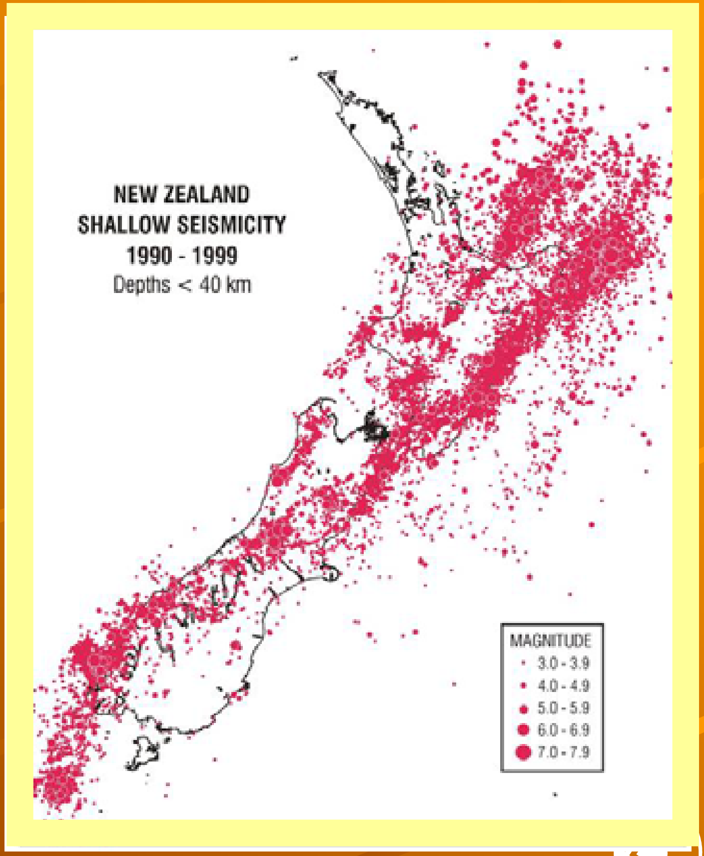


1985
2001
Auckland
1995
1931
1931
1843
1897
1863
1868
1934
1942
1942
1929
1968
1855
1848
Wellington
1888
1929
Christchurch
1938
2003
Dunedin
YEAR
Magnitude 7 and above
Magnitude 6.5 - 6.9
1979
1945


NEW ZEALAND
SHALLOW SEISMICITY
1990 - 1999
Depths < 40 km
MAGNITUDE
3.0 - 3.9
4.0 - 4.9
5.0 - 5.9
6.0 - 6.9
7.0 - 7.9


Active
Faults

In addition to the catalogue of faults, a **Background Seismicity Model** takes account of the distributed earthquake activity throughout the country.



Earthquake Loss Modelling

A Synthesis of Knowledge

1. What earthquakes are likely to occur?
2. How strong will the shaking be?
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Combine these to get loss probabilities

Magnitude and Intensity

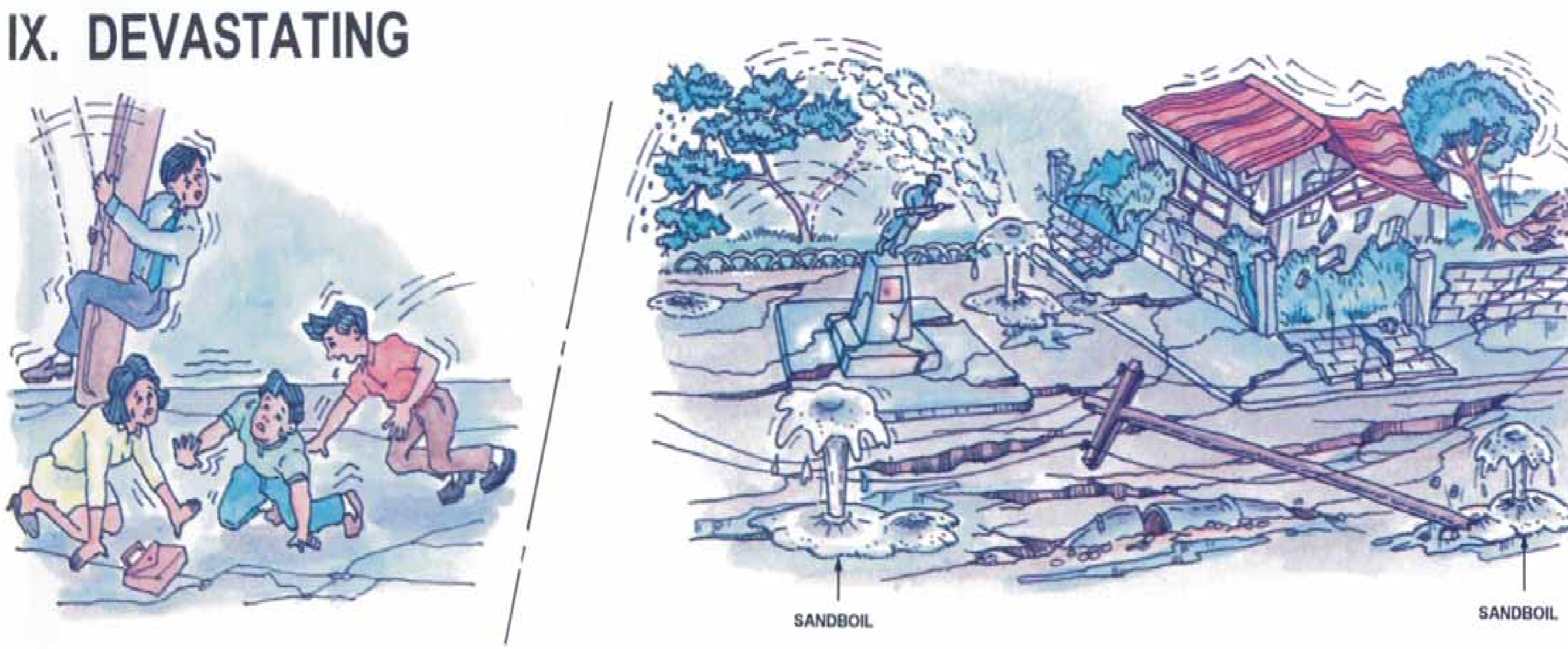
Throw a rock into a pond and you get waves.

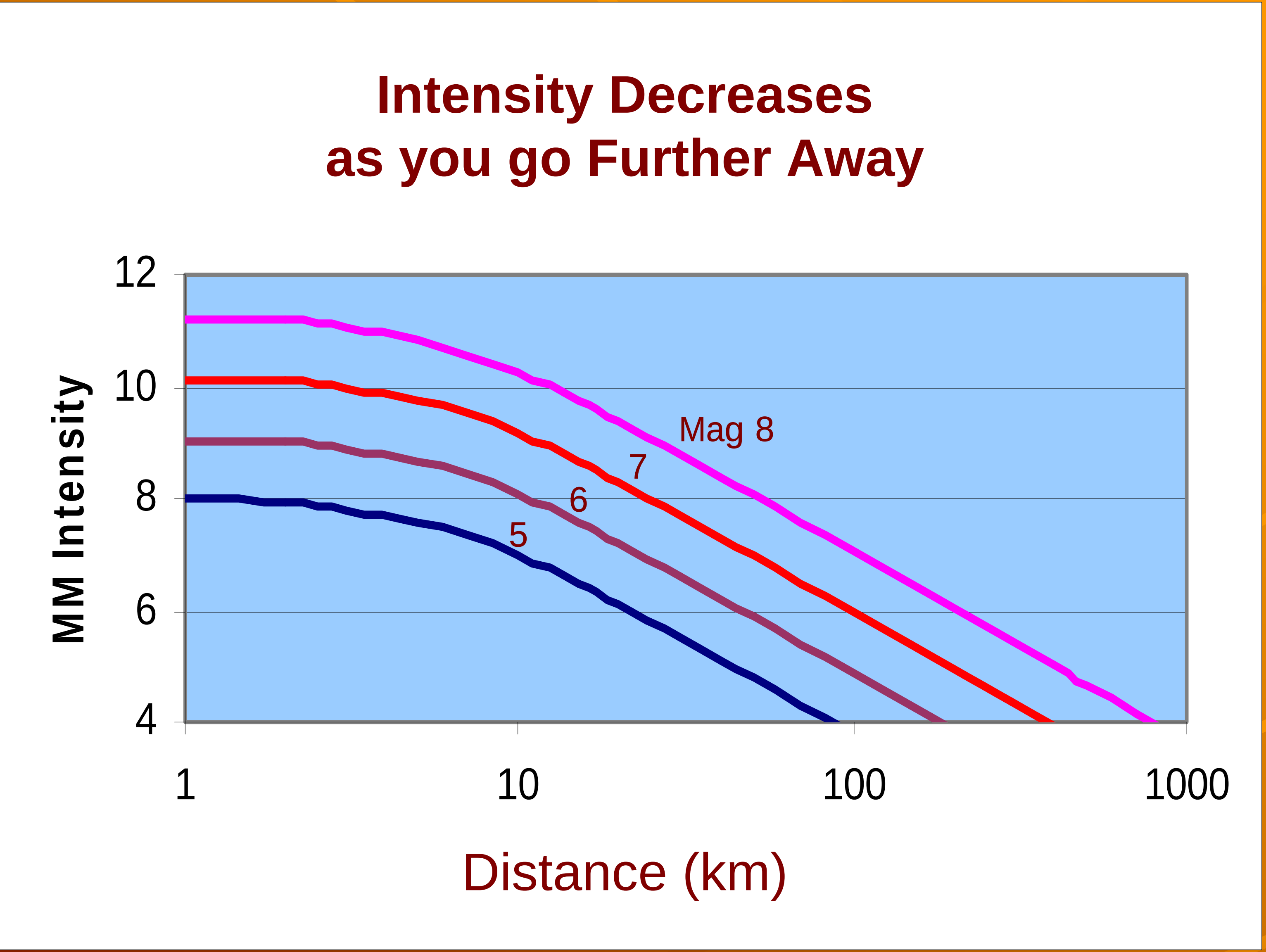
Magnitude (Richter scale) is like the size of the rock.

Intensity (Modified Mercalli scale) is like the height of the waves.

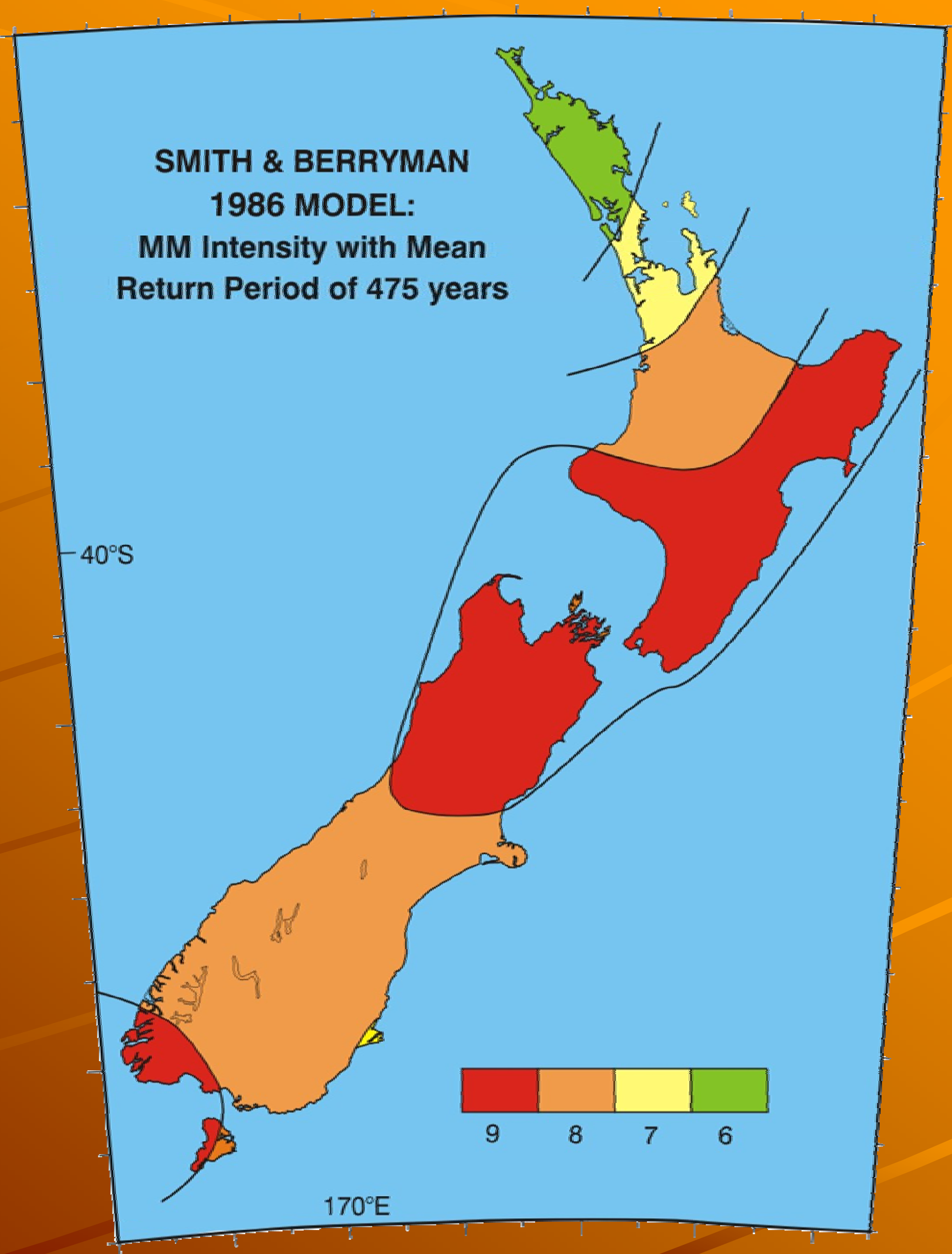
MM Intensity

MM Intensity

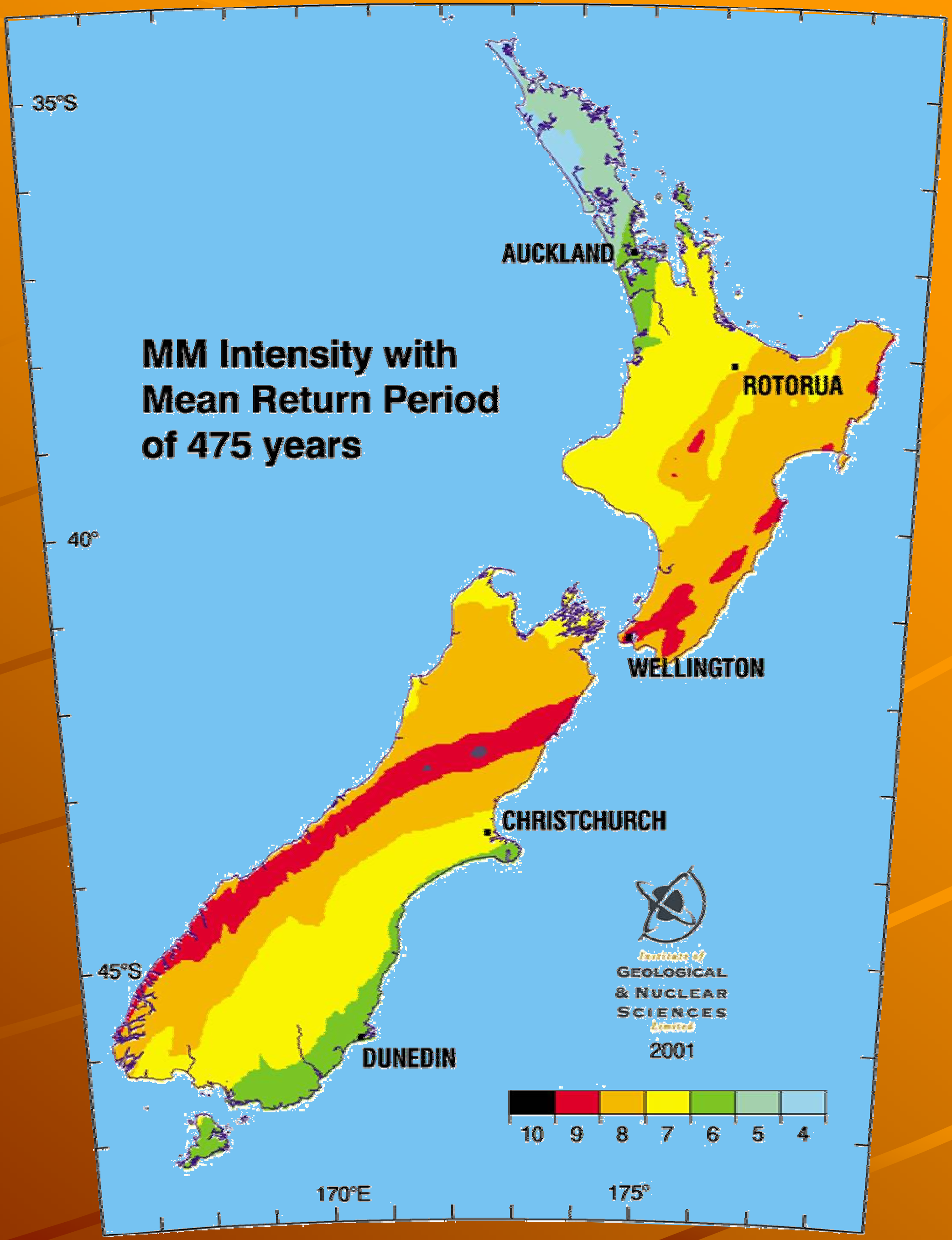




Intensity Decreases
as you go Further Away
MM Intensity
12
10
8
6
4
Mag 8
7
6
5
1
10
100
1000
Distance (km)



Some old work



And the
new version

Earthquake Loss Modelling

A Synthesis of Knowledge

1. What earthquakes are likely to occur?

2. How strong will the shaking be?

3. What will be the effects? (damage cost)

Combine these to get loss probabilities

Damage Ratio

$$\frac{\text{Cost of Repair}}{\text{Replacement Value of the Asset}}$$

A number between 0 and 1

Repair Cost = Value X DR

If we know the intensity and the building type we can estimate what the damage ratio is likely to be

Data from New Zealand earthquakes

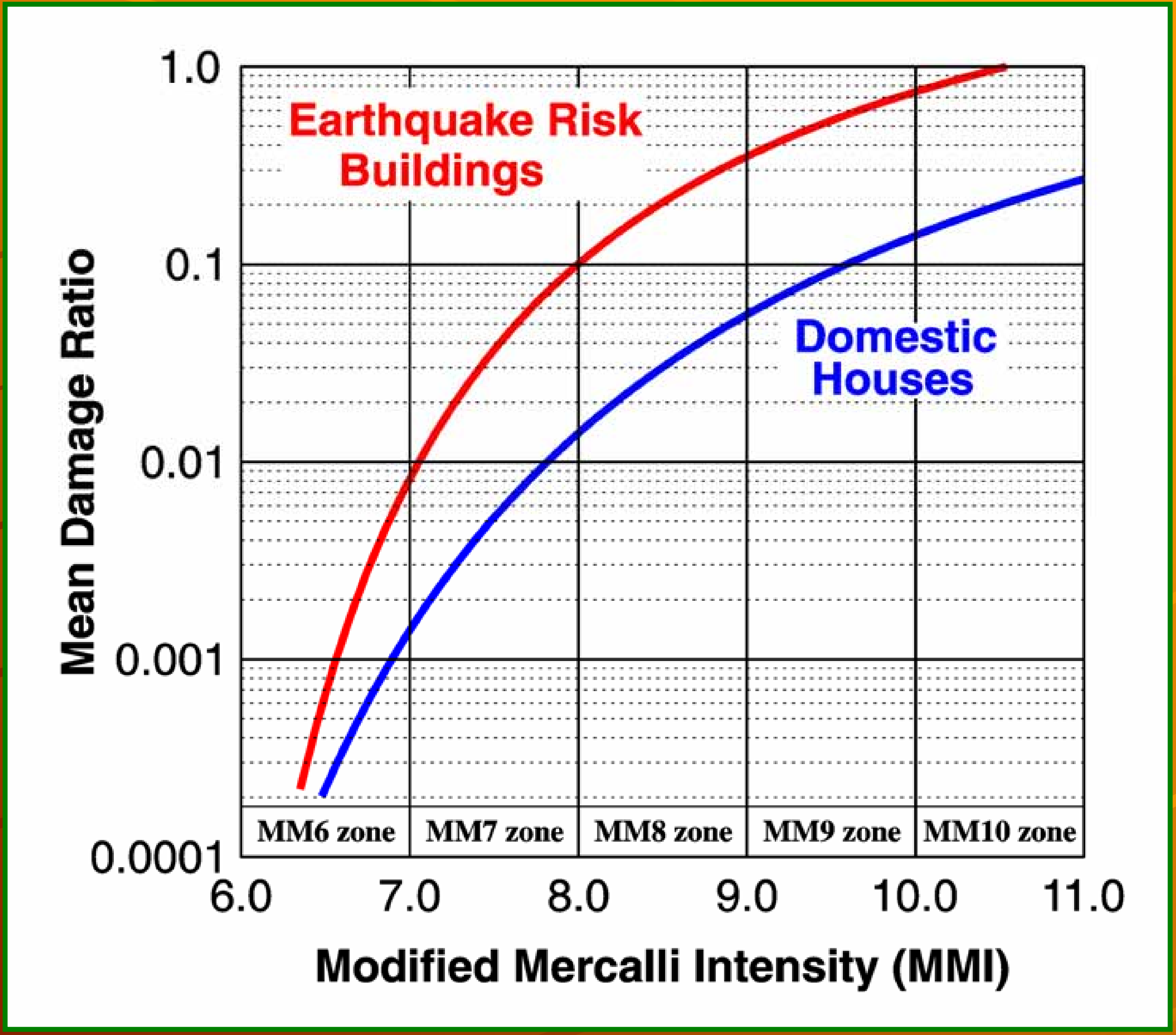
Hawke's Bay 1931

Inangahua 1968

Edgecumbe 1987

and others

Detailed insurance records are available



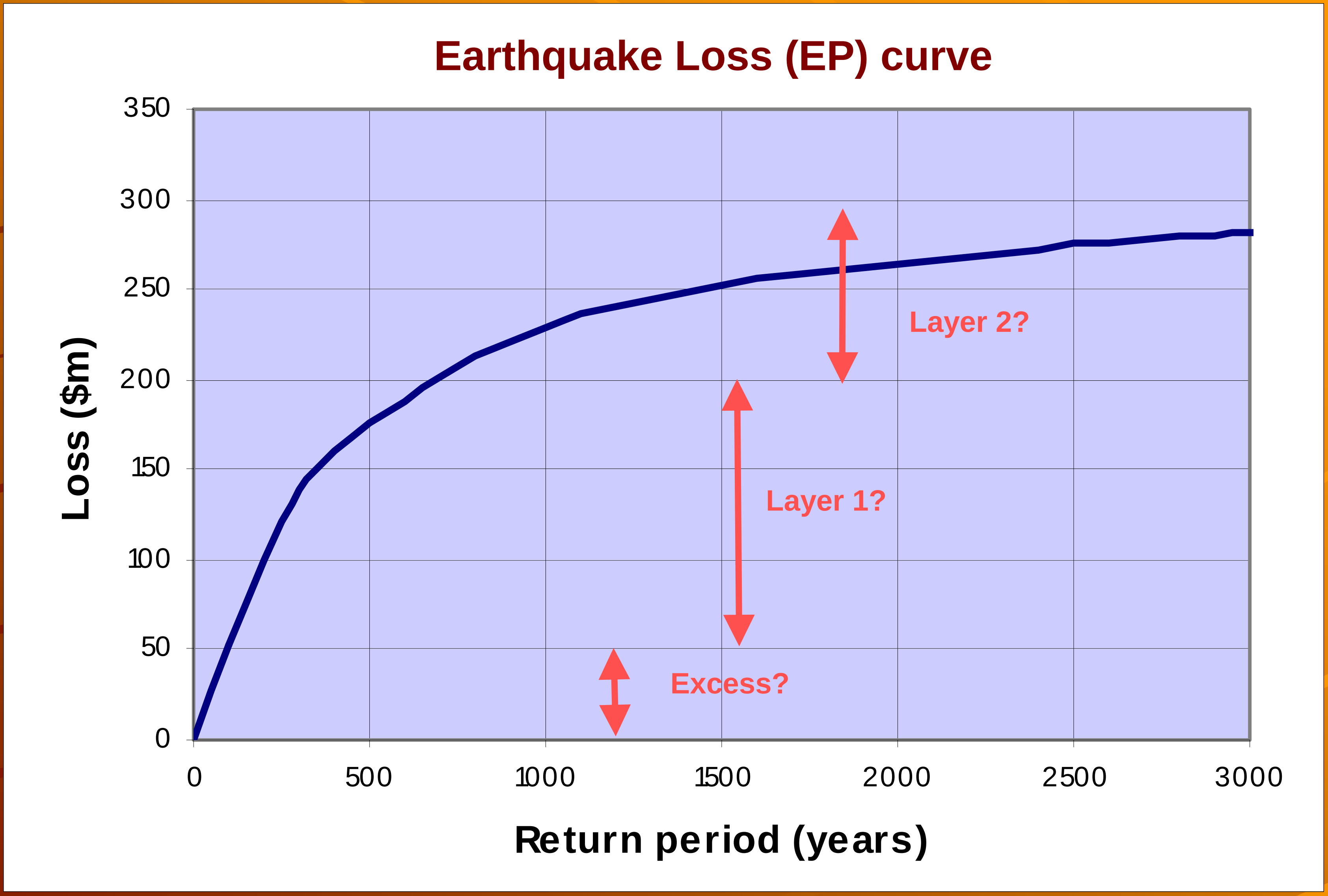
Earthquake Risk Buildings
Domestic Houses
Mean Damage Ratio
1.0
0.1
0.01
0.001
0.0001
MM6 zone
MM7 zone
MM8 zone
MM9 zone
MM10 zone
6.0
7.0
8.0
9.0
10.0
11.0
Modified Mercalli Intensity (MMI)

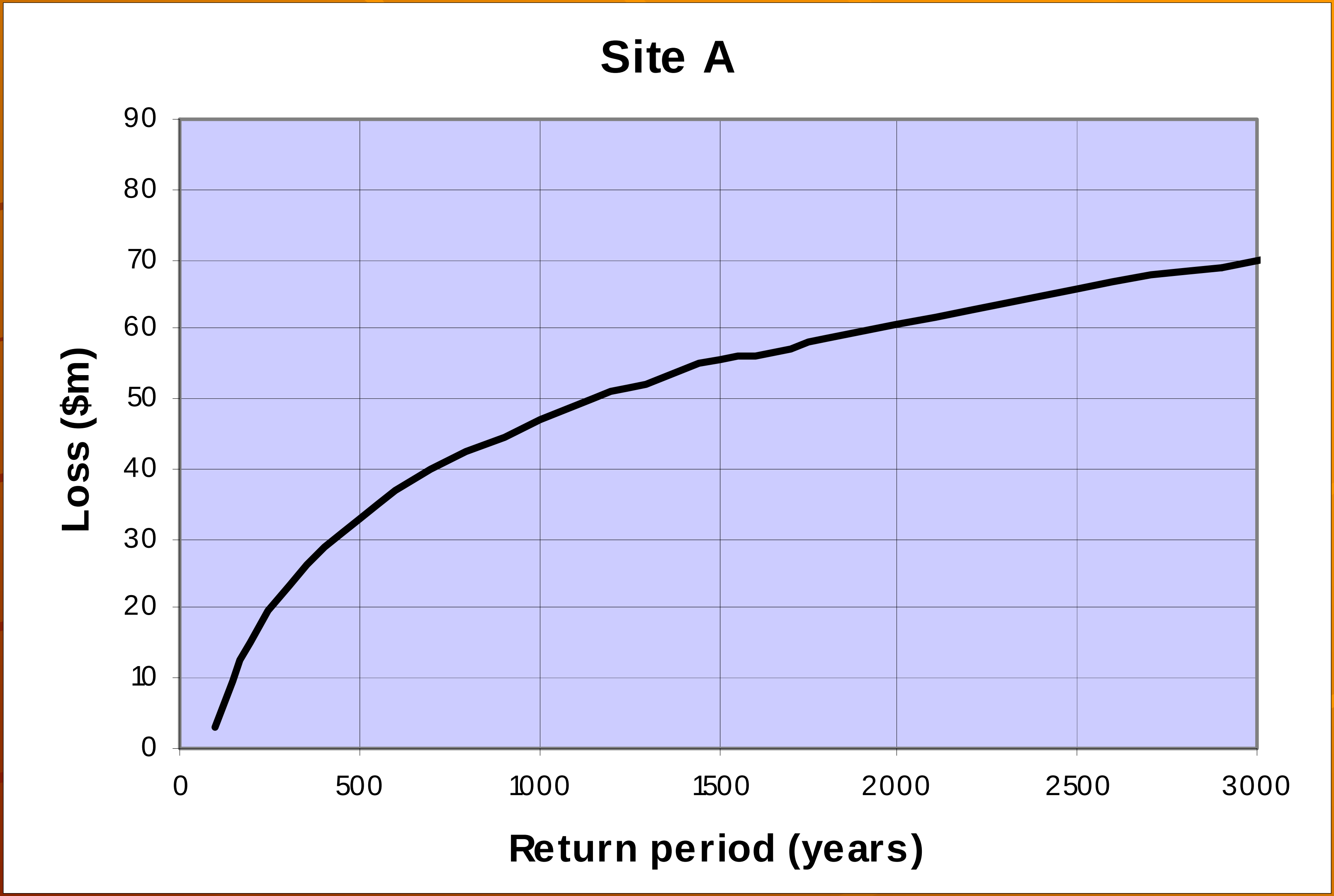
Earthquake Loss Modelling

A Synthesis of Knowledge

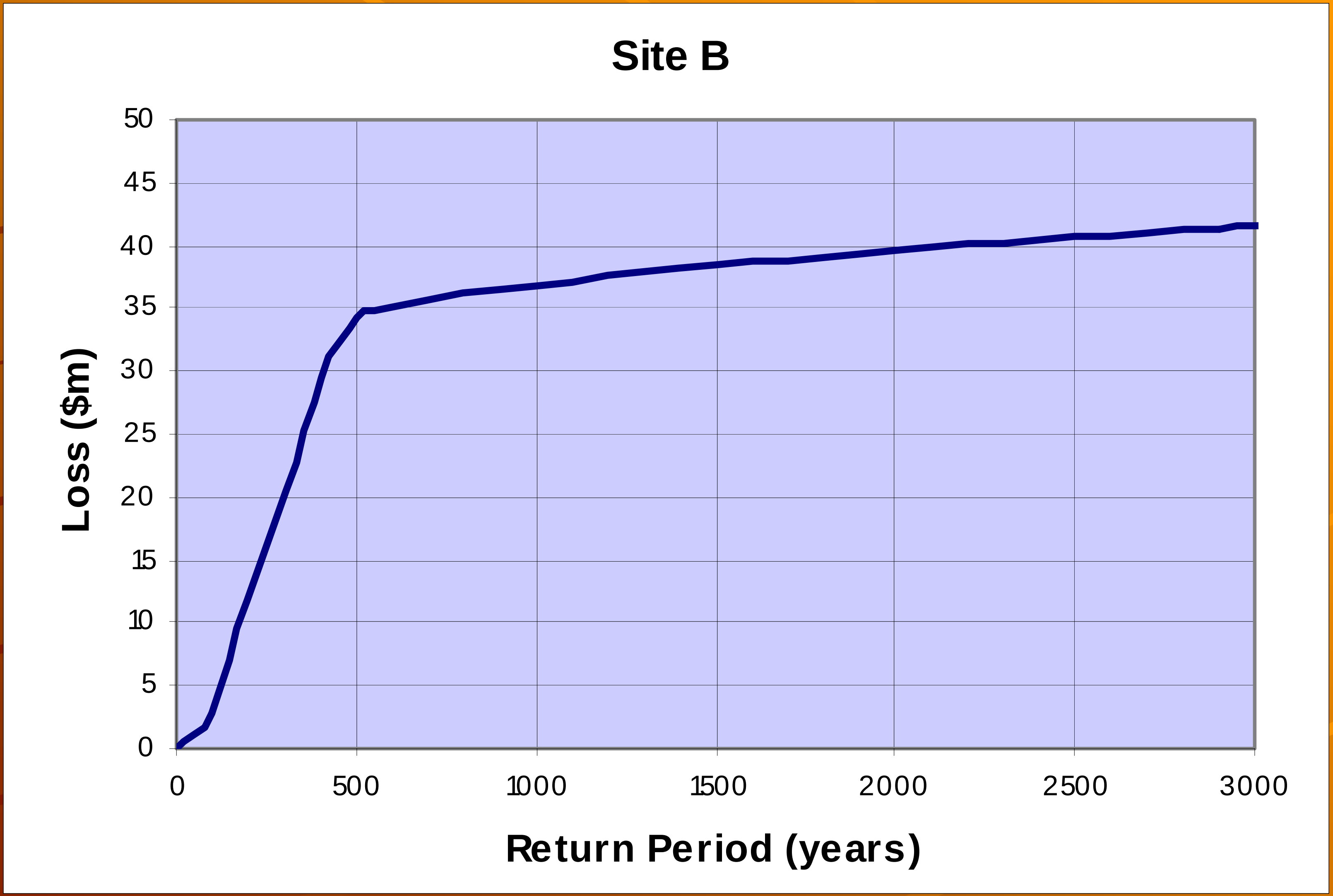
1. What earthquakes are likely to occur?
2. How strong will the shaking be?
3. What will be the effects?

Combine these to get loss probabilities

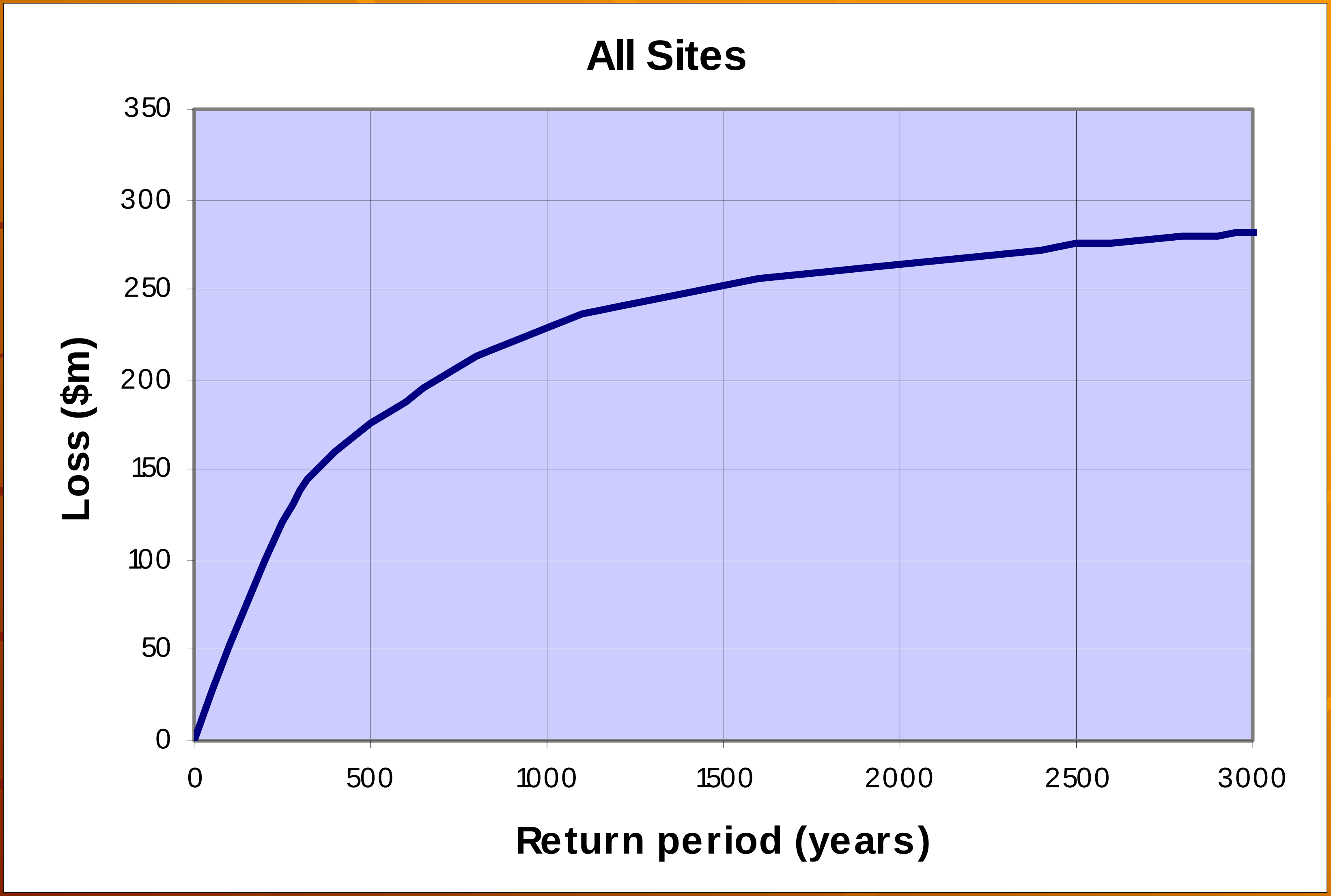

Earthquake Loss (EP) curve
Loss ($m)
350
300
250
200
150
100
50
0
0
500
1000
1500
2000
2500
3000
Return period (years)
Layer 2?
Layer 1?
Excess?



Site A
Loss ($m)
0
10
20
30
40
50
60
70
80
90
0
500
1000
1500
2000
2500
3000
Return period (years)



Site B
Loss ($m)
0
5
10
15
20
25
30
35
40
45
50
0
500
1000
1500
2000
2500
3000
Return Period (years)


All Sites
Loss ($m)
350
300
250
200
150
100
50
0
0
500
1000
1500
2000
2500
3000
Return period (years)

But insurers talk about

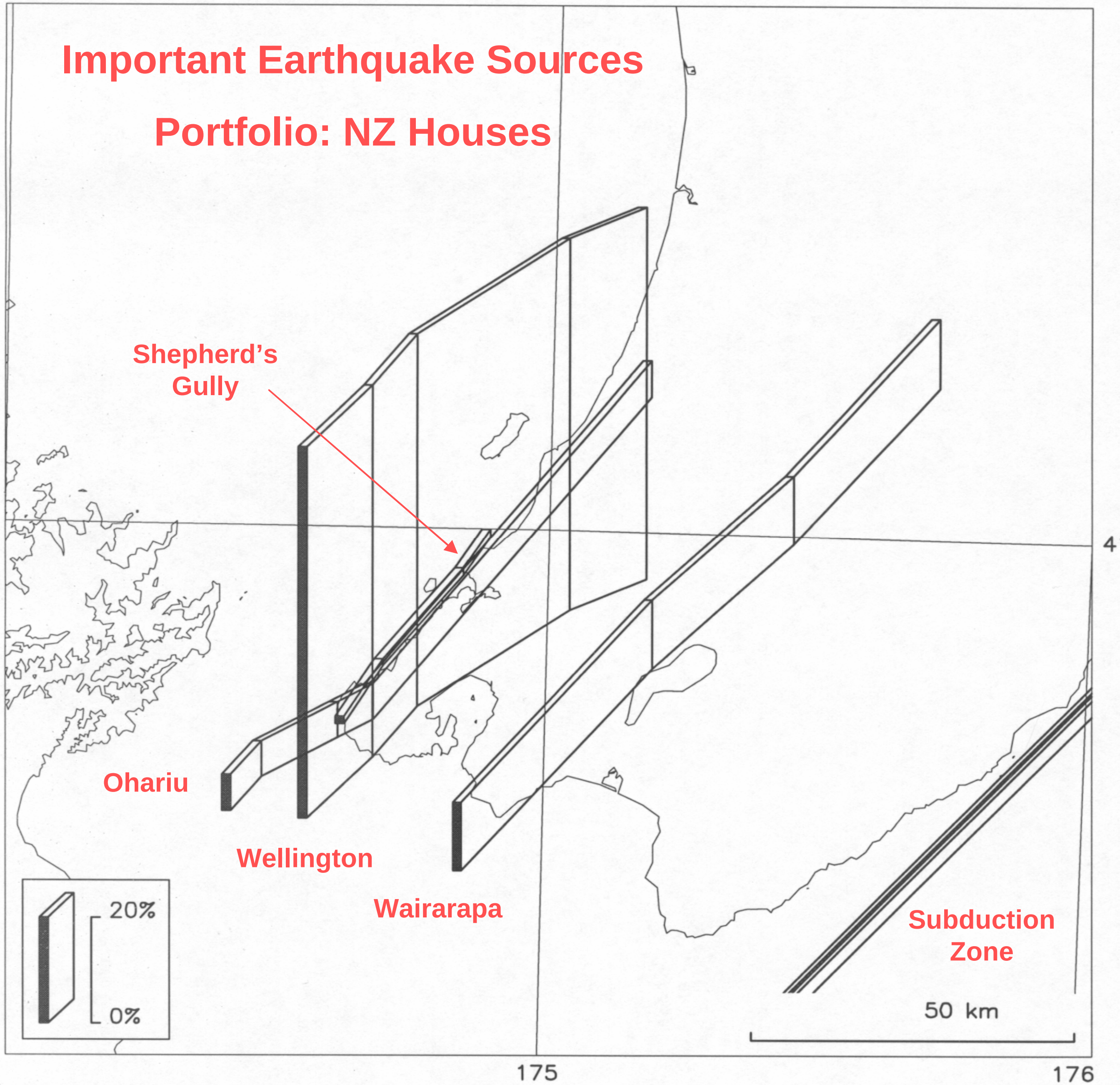
Probable Maximum Loss (PML)

What is that?

Can we estimate it?

Important Earthquake Sources

Portfolio: NZ Houses



The Wellington Fault

Magnitude 7.5

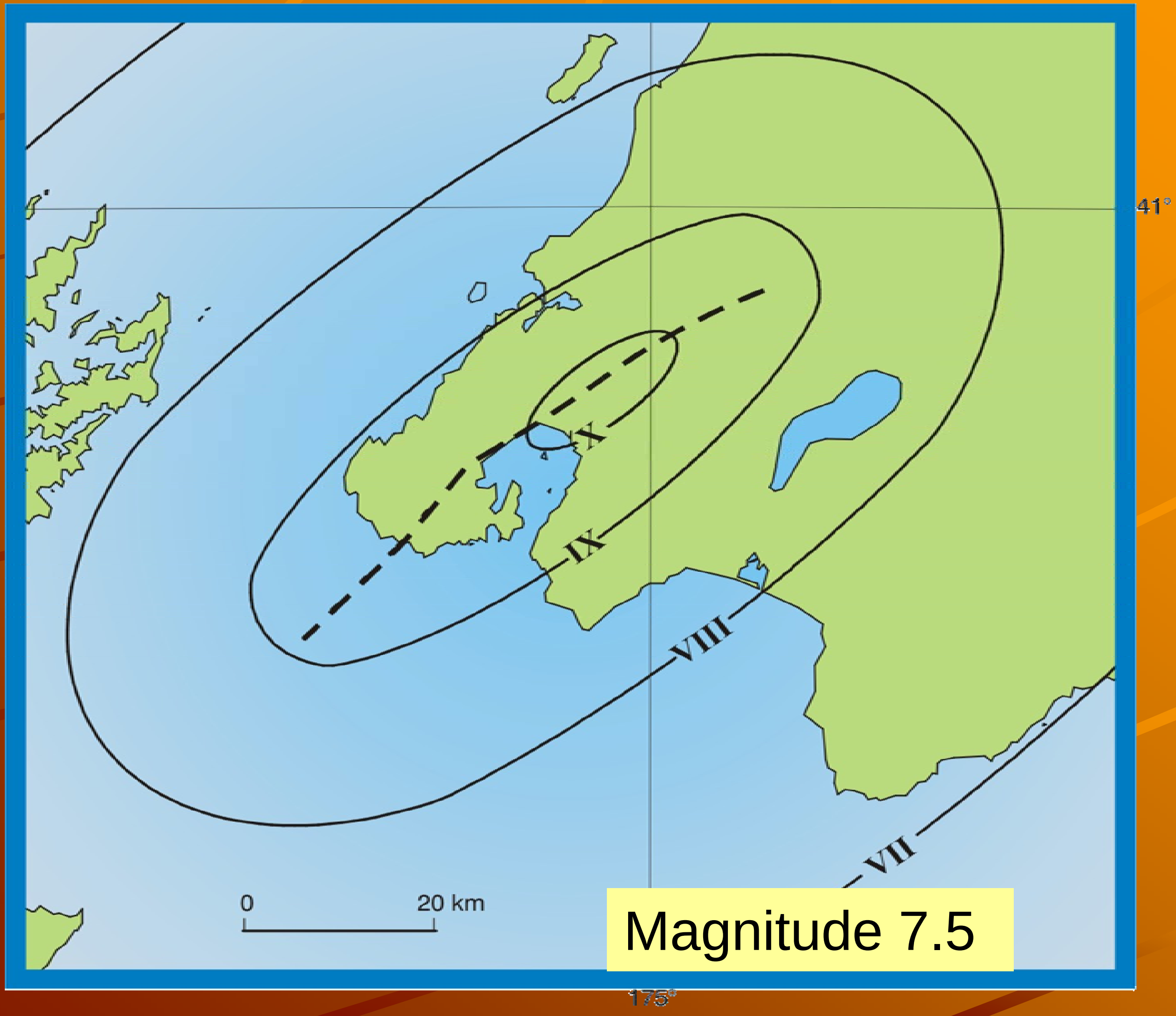
600 years (on average)

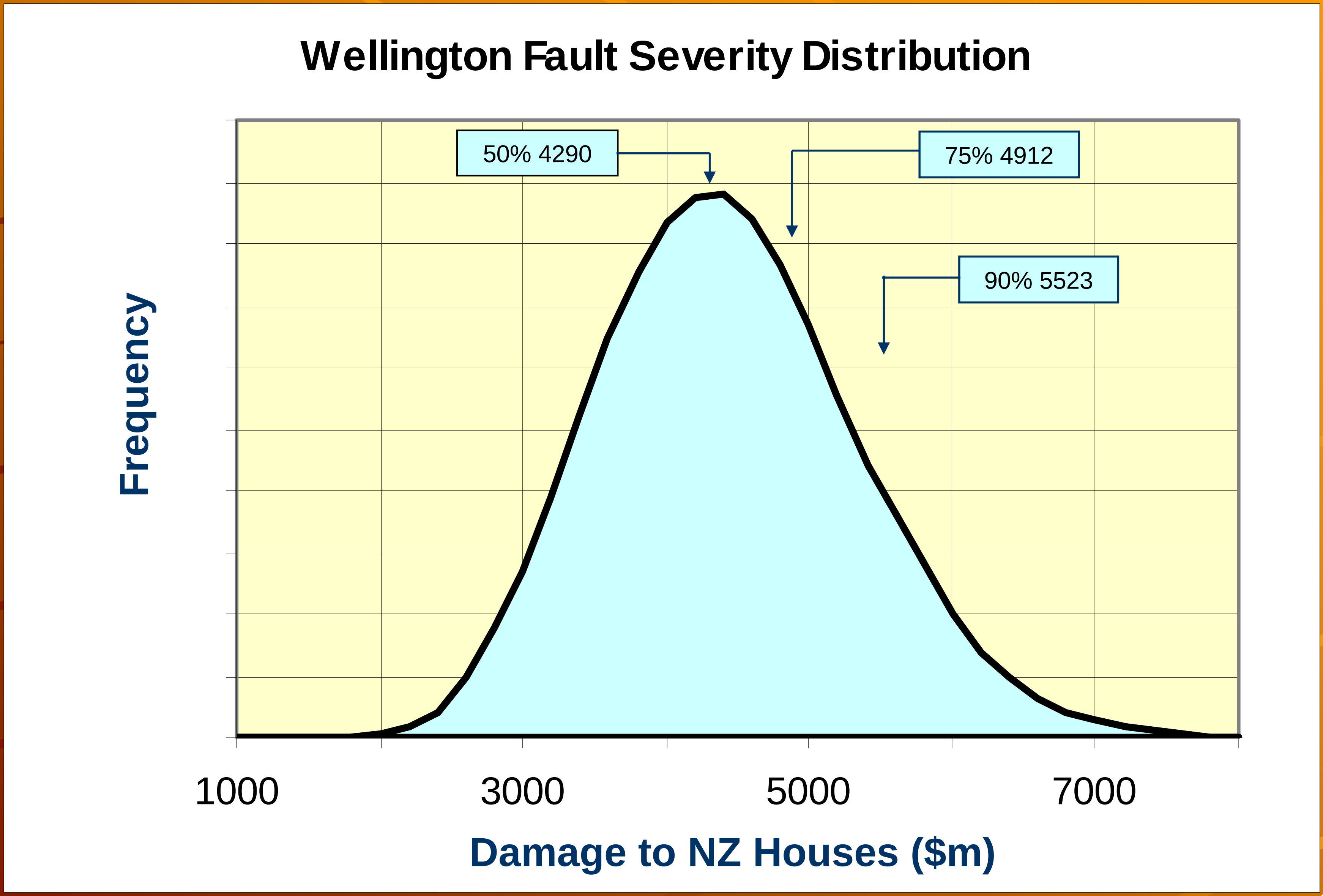
Last one ~ 400 years ago

Next one? Eventually Next week


Wellington

Wellington Fault Earthquake




Wellington Fault Severity Distribution
50% 4290
75% 4912
90% 5523
Frequency
1000
3000
5000
7000
Damage to NZ Houses ($m)

Earthquake Loss Modelling

Products

1. Loss curves – likelihood of $ loss for individual assets or portfolio
2. Scenarios – loss estimates for important earthquake sources
3. Basis for structuring the insurance

How Are Risk Management Decisions Made?

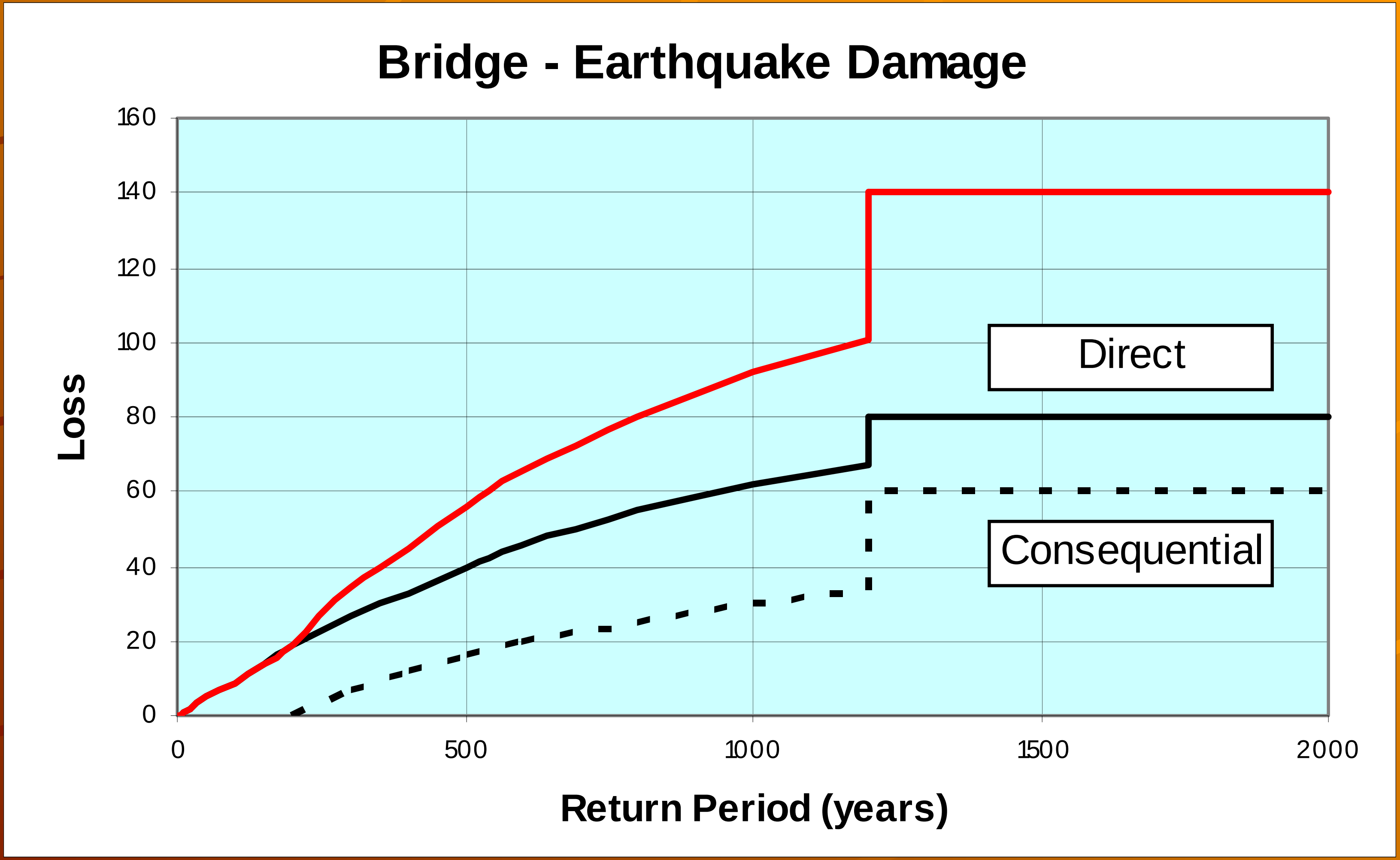
- How severe is the risk?
- Cost of mitigation programme?
- How will that reduce the risk?
- Priorities: allocating resources

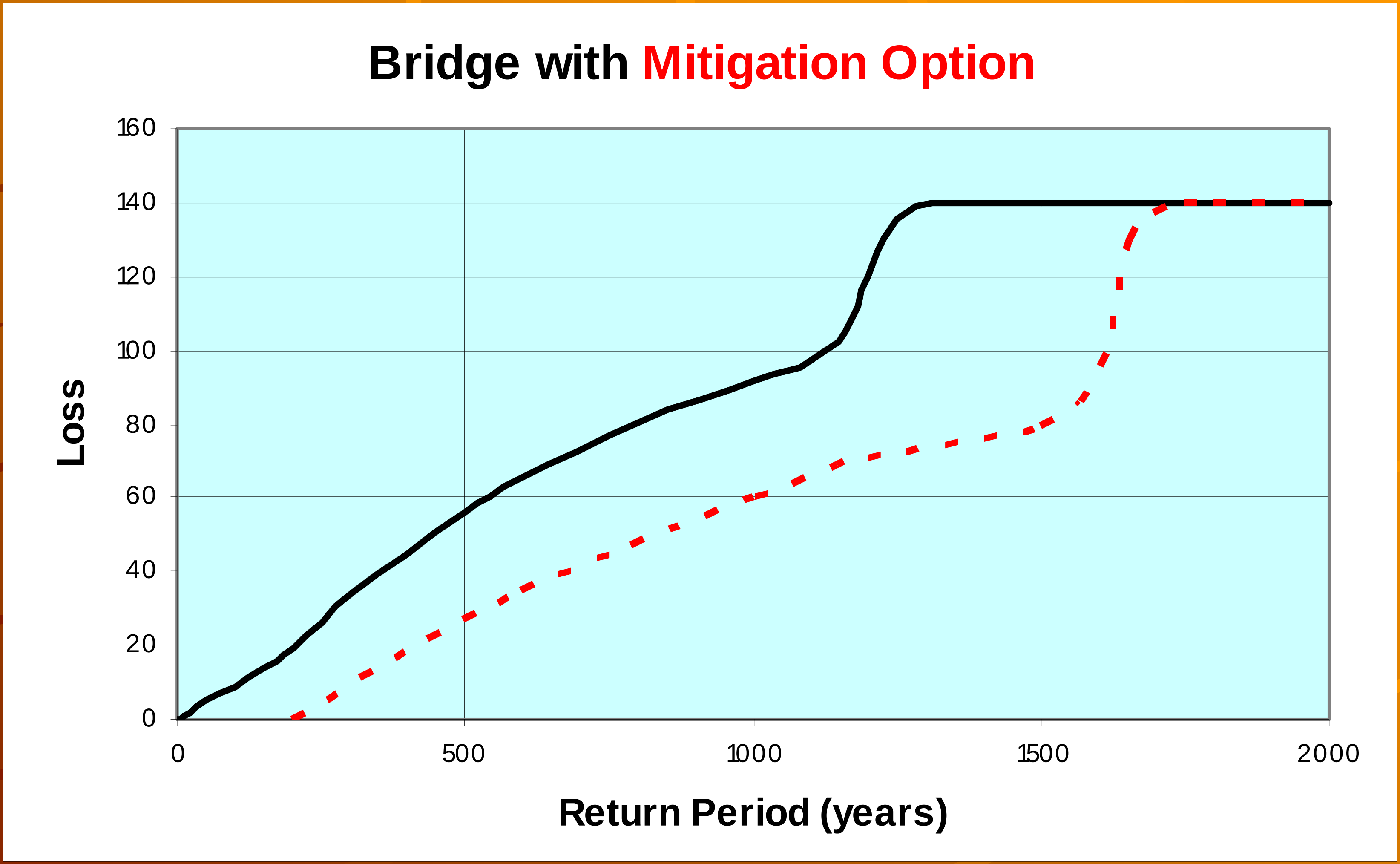
Risk Management Problem

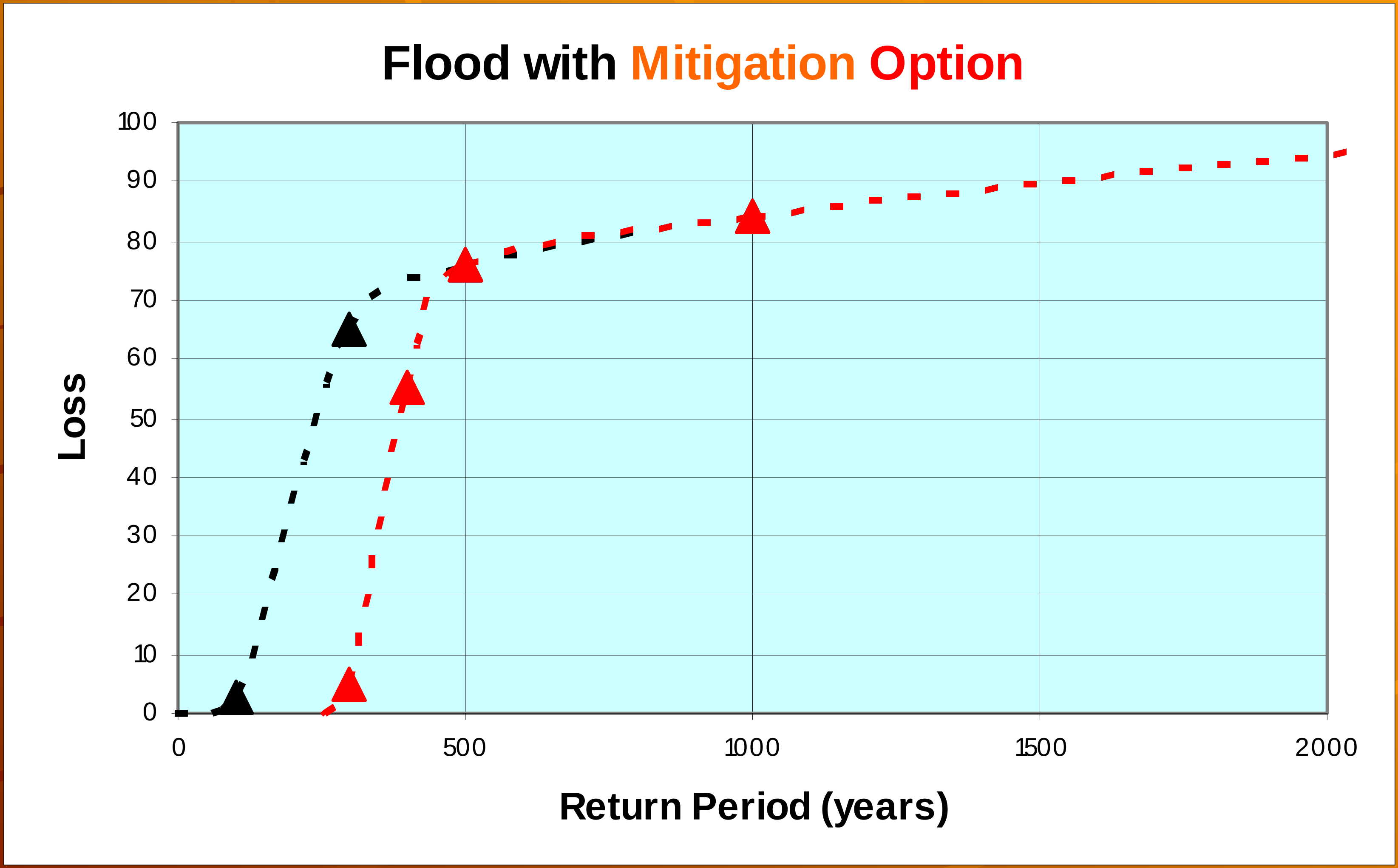
Our local Council wishes to address risk mitigation. The options for using our limited funding are:

(a) Strengthening a critical highway bridge against earthquake ($10m)

(b) Raising a stopbank to protect against flood ($5m)


Bridge - Earthquake Damage
Loss
Return Period (years)
0
20
40
60
80
100
120
140
160
0
500
1000
1500
2000
Direct
Consequential


Bridge with Mitigation Option
Loss
160
140
120
100
80
60
40
20
0
0
500
1000
1500
2000
Return Period (years)

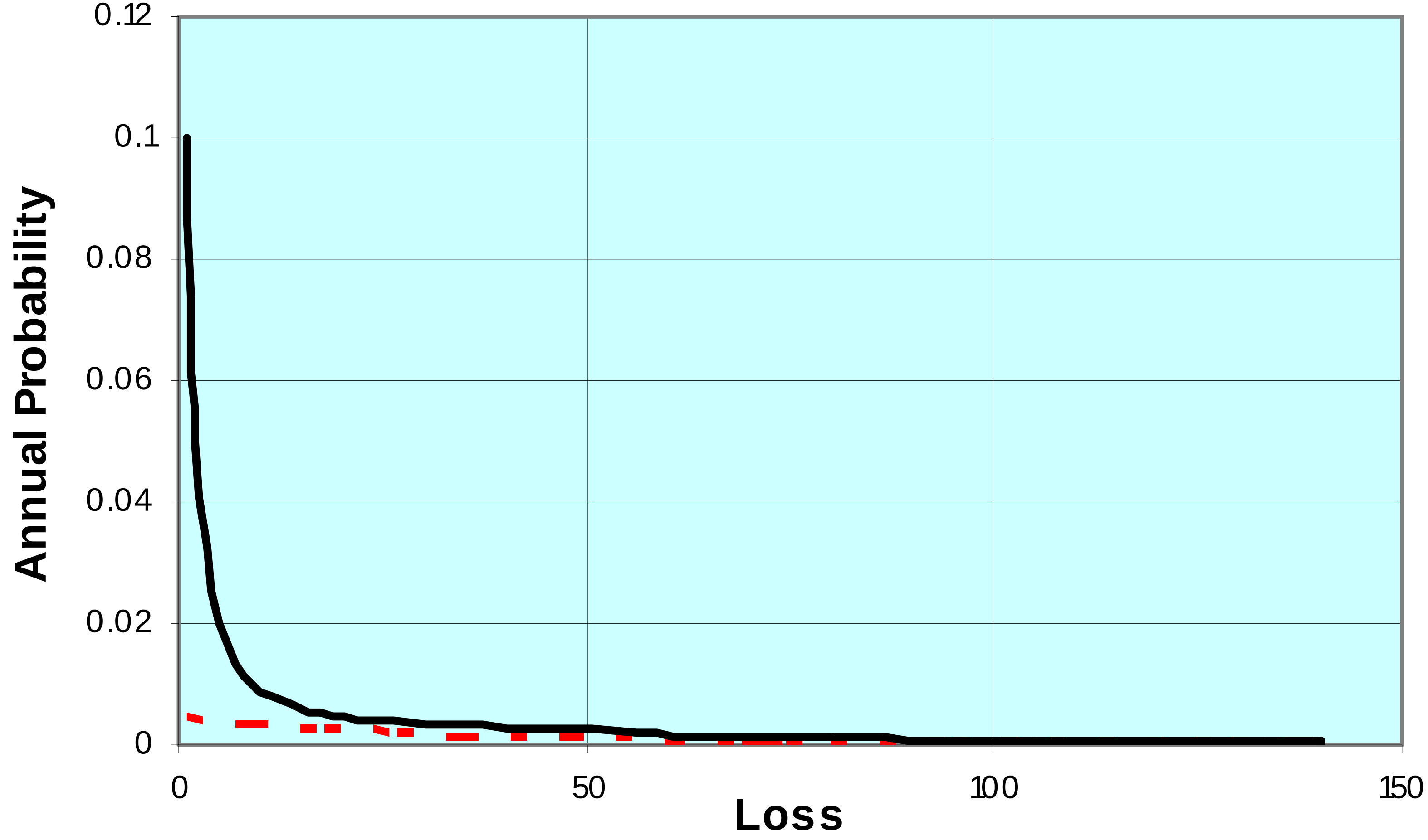

Flood with Mitigation Option
Loss
100
90
80
70
60
50
40
30
20
10
0
0
500
1000
1500
2000
Return Period (years)

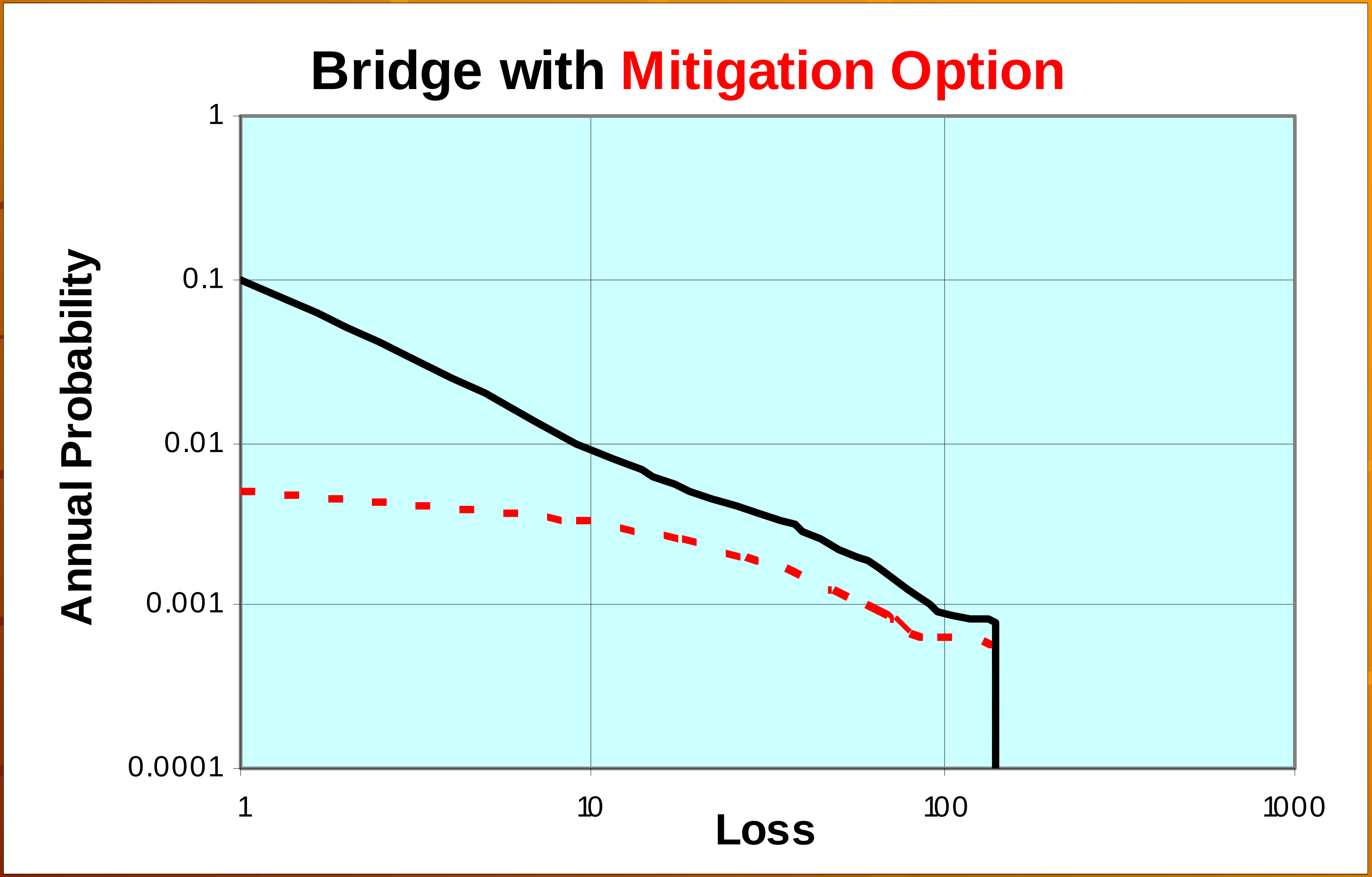
How do we measure the improvement?

Maybe we could use Average Annual Loss.

Statistical term: Expected Value

Bridge with Mitigation Option




Bridge with Mitigation Option
Annual Probability
1
0.1
0.01
0.001
0.0001
1
10
100
1000
Loss

Average Annual Loss

p(x) = probability density function for annual losses *x*

The Expected Value, or mean, of *x* is

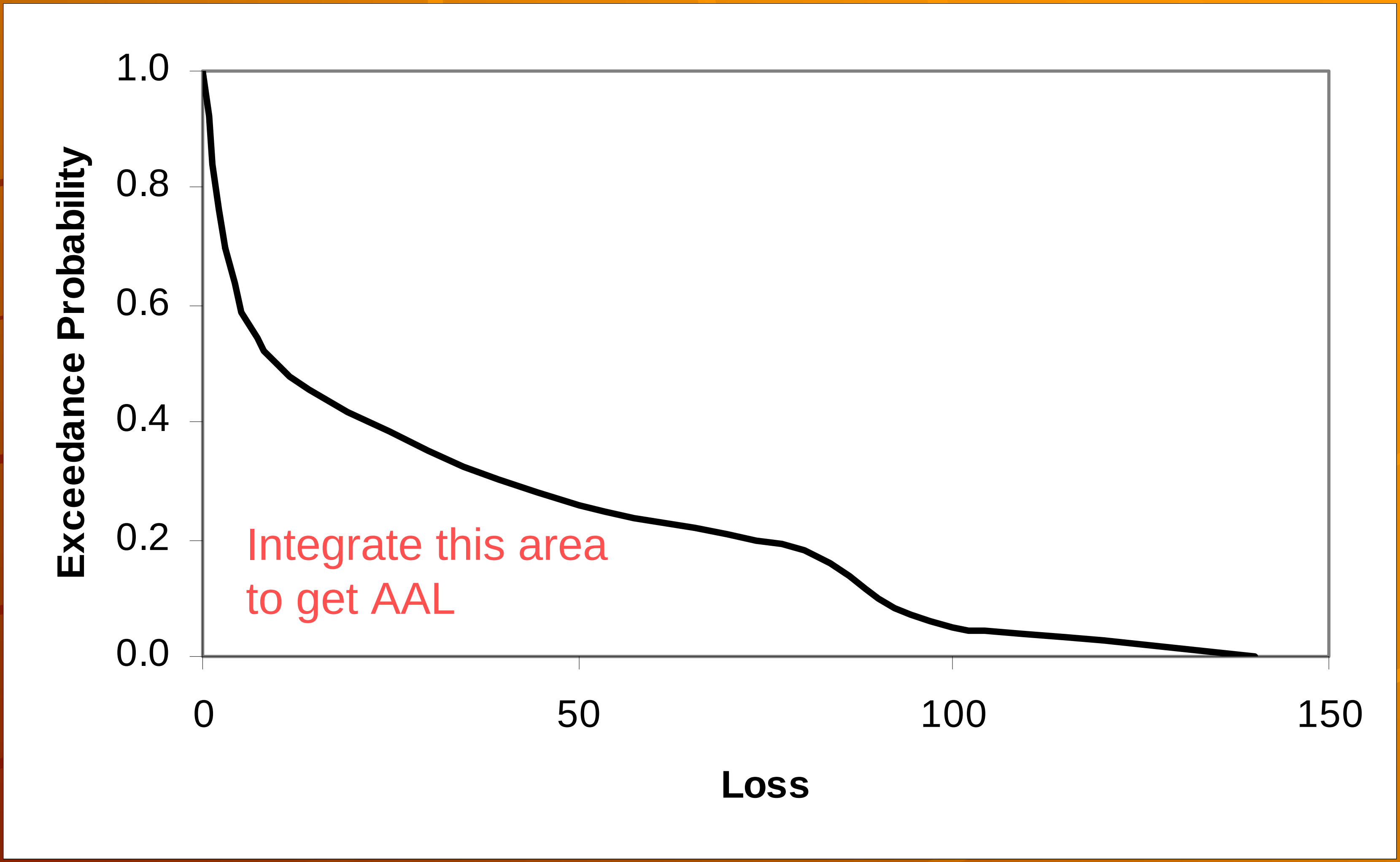
$$E[x] = \int_0^\infty x p(x) dx$$

Which can also be written as

$$E[x] = \int_0^\infty P(x) dx$$

P(x) is the cumulative probability distribution, and this is helpful because we can't evaluate p(x).

Average Annual Loss (Expected Value)



Average Annual Loss ($m)

	Present	Proposed
Bridge ($10m)	0.63	0.16
Stopbank ($5m)	0.38	0.20

What do these numbers mean?

The Fallacy of the Expected Value

~~**Risk = Probability X Consequences**~~

- Highways
- Telephones
- Emergency Services

“A single number is not a big enough concept to communicate the idea of risk”

Kaplan & Garrick (1981)

How do we measure the improvement?

- Conditional Expected Value is the expected loss within a given probability range
- So we could evaluate the 10-year, 100-year and 1000-year losses, say, and see how they change with mitigation

Conditional Expected Value of Loss

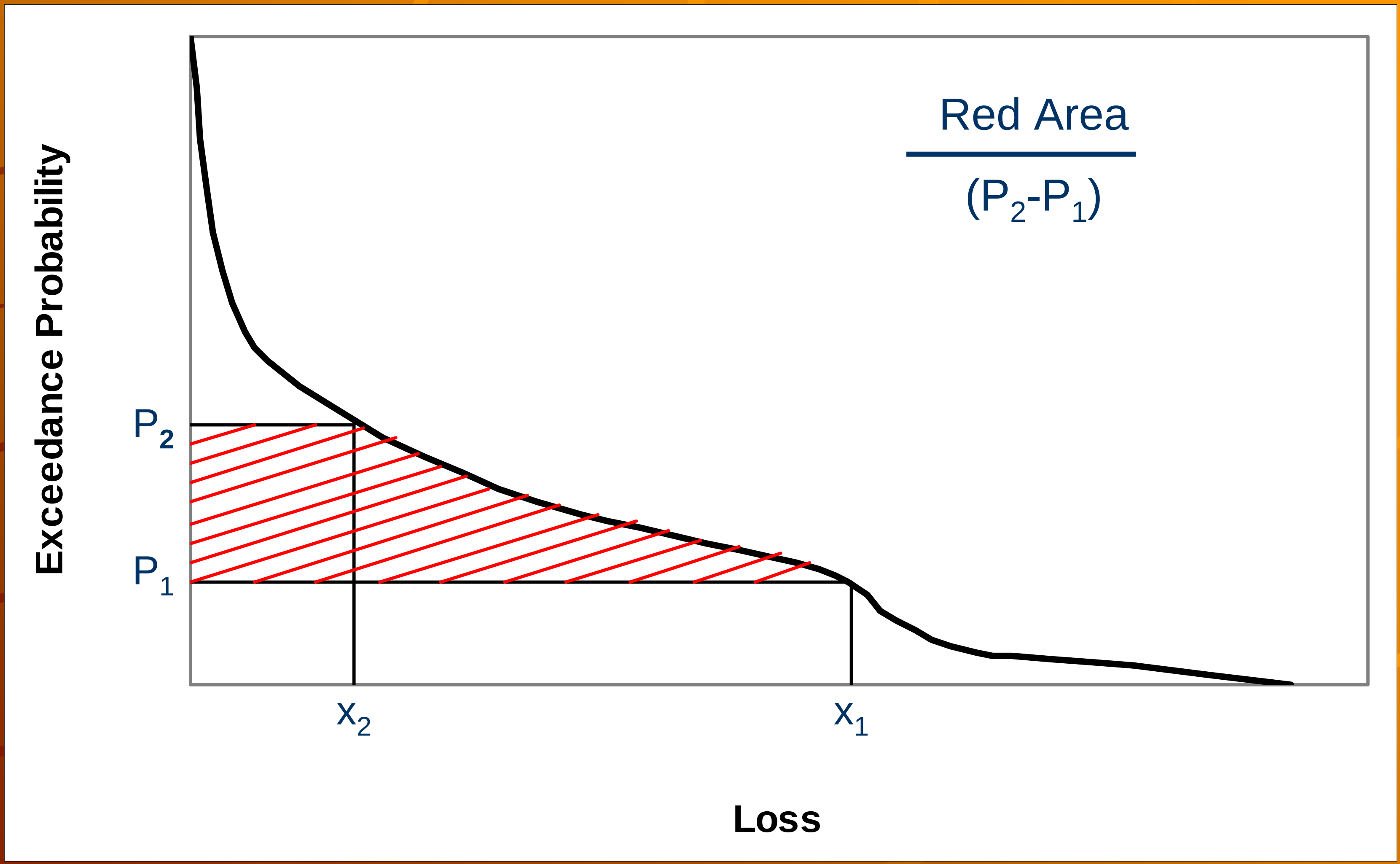
If probabilities P_1 and P_2 correspond to losses x_1 and x_2, we can write

$$E[x \mid P_1 < P < P_2] = \frac{\int_{x_2}^{x_1} x p(x) dx}{\int_{x_2}^{x_1} p(x) dx}$$

Which turns out to be equivalent to

$$E[x \mid P_1 < P < P_2] = \frac{\int_{P_1}^{P_2} x(P) dP}{P_2 - P_1}$$

Conditional Expected Value



We can always do the integral because:

1. The cumulative probability P(x) is monotonically decreasing, so we can always find x(P).

2. Even if we only know x(P) at a few points, we can interpolate between them in order to perform the integral.

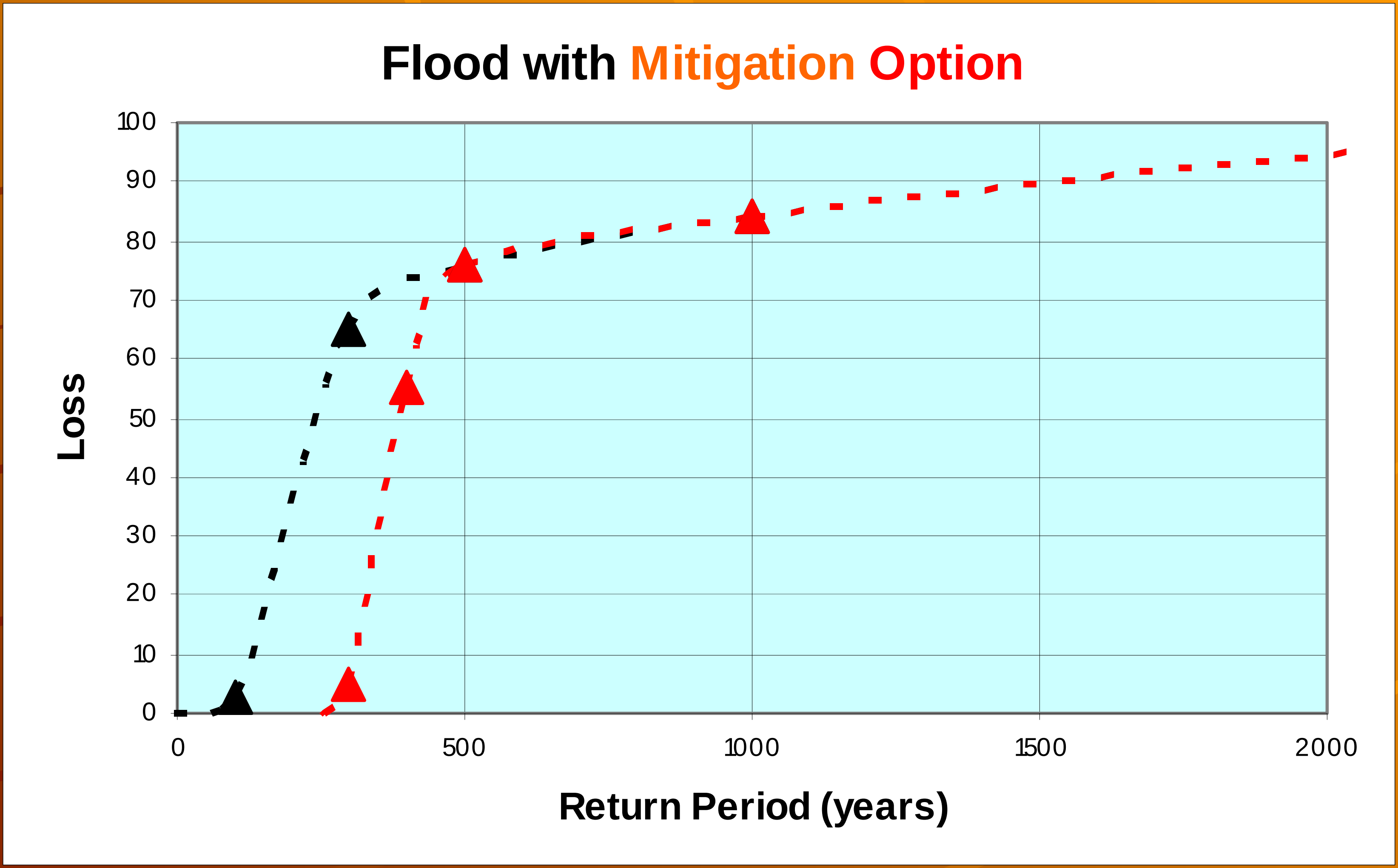
The main thing is: we don't need to differentiate P(x) and find the pdf p(x).

The 10-year, 100-year and 1000-year losses are expected losses for events in selected probability ranges

	P_1	P_2	Ret.Per.
10-yr	0.032	0.32	3.2 - 32
100-yr	0.0032	0.032	32 - 320
1000-yr	0.00032	0.0032	320 - 3200

Conditional Expected Losses

	Bridge		Stopbank	
	Present	$10m	Present	$5m
10 yrs	0.55	0	0	0
100 yrs	8	0.27	4.6	0.06
1000 yrs	75	46	79	66
AAL	0.63	0.16	0.38	0.20


Flood with Mitigation Option
Loss
100
90
80
70
60
50
40
30
20
10
0
0
500
1000
1500
2000
Return Period (years)

Regional Riskscape

A joint research programme between:
Institute of Geological & Nuclear Sciences
National Institute for Water and Atmospheric Research.

Funded by the Foundation for Research, Science & Technology.

Earthquake, volcano, flood, storm, tsunami.

Three regions in a pilot study.

Plan to produce a tool to assist risk managers anywhere in New Zealand.

Losses we Might Model

Direct damage

Consequential damage

Casualties and injuries

Environmental effects

etc.

We can use the loss curve
to make informed decisions

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