GROUND SHAKING HAZARD WELLINGTON

NOTES TO ACCOMPANY

SEISMIC HAZARD MAP SERIES: GROUND SHAKING HAZARD MAP SHEET 1 WELLINGTON (FIRST EDITION) 1:20000

OCTOBER 1992

Publication WRC/PP-T-92/45

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POLICY AND PLANNING DEPARTMENT

1. INTRODUCTION

1.1 BACKGROUND

The occurrence of earthquakes in the Wellington Region is inevitable due to its location at the boundary of two crustal plates. Earthquakes have the potential to cause significant adverse effects within the Region, including loss of life, injury, and social and economic disruption. In recognition of these potential effects, the Wellington Regional Council initiated a project in 1988 to:

- Assess the risks posed by earthquakes.
- Identify mitigation options.
- Implement measures to ensure that the level of risk is acceptable.

The first step in the project is to define the characteristics of the hazard. Information on the type and magnitude of possible effects, the probability of these occurring and the location of the effects within the Region is required. For the purposes of the project, *earthquake hazard* has been divided into a number of separate but interrelated components, including:

- Ground shaking.
- Surface fault rupture.
- Liquefaction and ground damage.
- Landsliding.
- Tsunami.

Although not all the effects will occur during every earthquake, and many will be localised, all components must be considered to obtain a complete picture of earthquake hazard.

1.2 PURPOSE OF MAP AND BOOKLET

A series of six map sheets, with accompanying booklets, has been compiled to describe the *ground shaking hazard* for the main metropolitan areas in the Region (refer to Index Map on accompanying map sheet):

- Sheet 1 - Wellington.
- Sheet 2 - Porirua and Tawa.
- Sheet 3 - Lower Hutt.
- Sheet 4 - Upper Hutt.
- Sheet 5 - Paekakariki, Paraparaumu, Waikanae and Otaki.
- Sheet 6 - Featherston, Greytown, Carterton and Masterton.

The purpose of the maps is to show the geographic variation in ground shaking hazard that could be expected during certain earthquake events. **The map sheets and booklets have been compiled from Wellington Regional Council reports and detailed reports prepared for the Wellington Regional Council by DSIR Geology and Geophysics, Land Resources and Physical Sciences, and Victoria University of Wellington.** A list of the reports is given in Appendix 1.

The intention of the map and booklet series is to raise public awareness of ground shaking hazard in the Wellington Region. The information should be useful to a range of potential users, including land use planners, civil defence organisations, land developers, engineers, utility operators, scientists and the general public.

Information on active faults in the western part of the Region has been published in a map series by the Wellington Regional Council - *Major Active Faults of the Wellington Region* (Map sheets 1, 2 and 3: 1991). Tsunami hazard information for Wellington Harbour is also available.

1.3 BOOKLET STRUCTURE

This booklet is divided into four main parts. Part 1 provides background information on the study. Part 2 outlines the hazard assessment approach and details the mapping methodology. Parameters used to quantify the hazard zones are also discussed. Part 3 states the assumptions and limitations that determine the certainty with which the hazard zones can either be mapped or quantified. A brief summary is given in Part 4.

Technical terms are defined in Appendix 2.

2. HAZARD ASSESSMENT

2.1 DATA SOURCES

The geographic variation in earthquake ground shaking was defined using geological and geotechnical information from drillhole logs, microearthquake records, strong motion earthquake records and penetrometer logs.

The distribution of geological materials in the Wellington City area was mapped primarily on an assessment of 804 drillhole logs. The shaking response of a representative suite of these materials was assessed at 27 sites using records from 30 microearthquakes, and at 12 sites using strong motion earthquake records from a Magnitude 6 and a Magnitude 7 earthquake. The properties of the *softer* geological materials were further quantified using four cone penetrometer and three seismic-cone penetrometer probings.

2.2 EARTHQUAKE SCENARIOS

The Wellington Region is located across the boundary of the Pacific and Australian plates (Figure 1). As a consequence, the Region is cut by four major active faults, and is frequently shaken by moderate to large earthquakes (Figures 2 and 3).

Because no single earthquake event adequately describes the potential ground shaking hazard in the Region two earthquake scenarios were used to define the hazard.

Scenario 1 is for a large, distant, shallow earthquake that produces Modified Mercalli intensity (MM) V-VI on bedrock (Appendix 3). It is expected that this type of earthquake will produce the largest variation in ground response. Scenario 1 implies minor damage to structures founded on the *best* sites and significant damage to certain structures on the *worst* sites. An example of such an event would be a Magnitude (M) 7 earthquake centred about 100 kilometres from the study area at a depth of less than 30 kilometres. Twenty years is a minimum estimate for the return time of a Scenario 1 event. This return time is derived from the historical occurrence of both large earthquakes and moderate sized local events. A maximum estimate is 80 years, which is the return time of MM VII or greater shaking at bedrock sites in the Wellington Region.

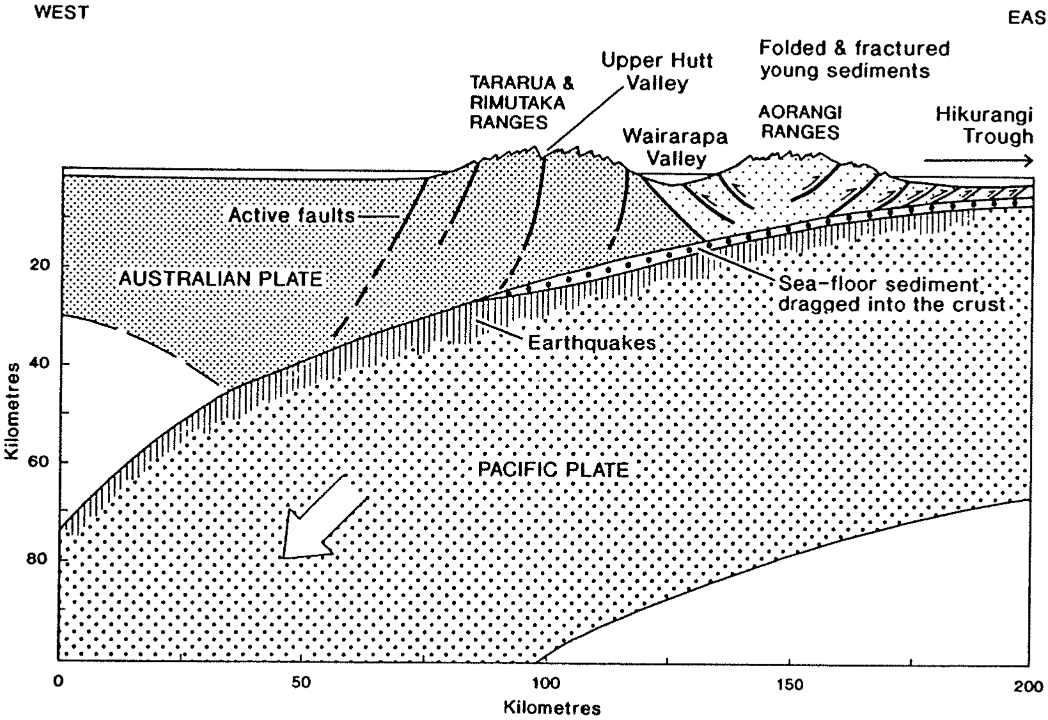

Figure 1: Source of earthquakes at plate boundary and along active faults. (After Stevens, 1991).

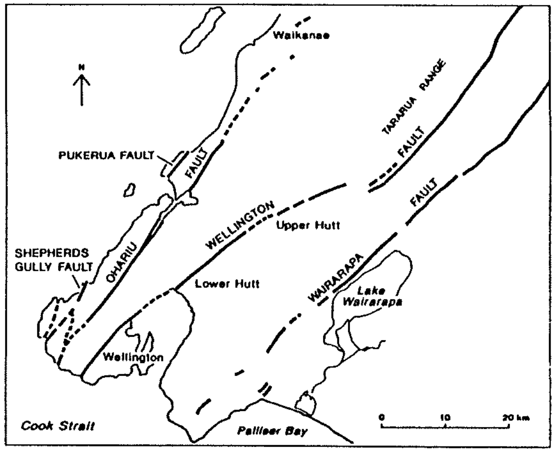

Figure 2: Active faults in the western part of the Wellington Region.

Scenario 2 is for a large earthquake centred on the Wellington-Hutt Valley segment of the Wellington Fault. Rupture of this segment is expected to be associated with a Magnitude 7.5 earthquake at a depth less than 30 kilometres, and up to 5 metres of horizontal and 1 metre vertical displacement at the ground surface. The return time for such an event is about 600 years and the probability of this event occurring in the next 30 years is estimated to be 10 percent. The values for near-source shaking resulting from a Scenario 2 earthquake are given with less certainty. This is because there are so few near-source ground motion data from large

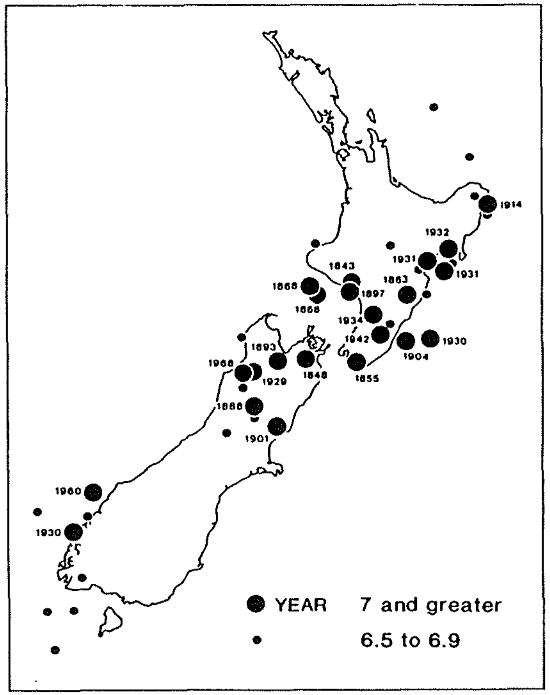

Figure 3: Epicentres of shallow earthquakes of magnitude 6.5 and greater since 1840 (Van Dissen et al, 1992).

earthquakes, and factors such as proximity to local asperities along the rupture plane and random cancellation and reinforcement of seismic waves can locally suppress the effects caused by near-surface geological deposits. Furthermore, amplification of some local geological deposits will not occur at particular ground shaking frequencies and strengths.

2.3 MAPPING METHODOLOGY

2.3.1 Surface geology

The distribution of Quaternary sediments was summarised in a series of maps at scales of 1:10000 and 1:20000. The maps, based on the drillhole logs, depict:

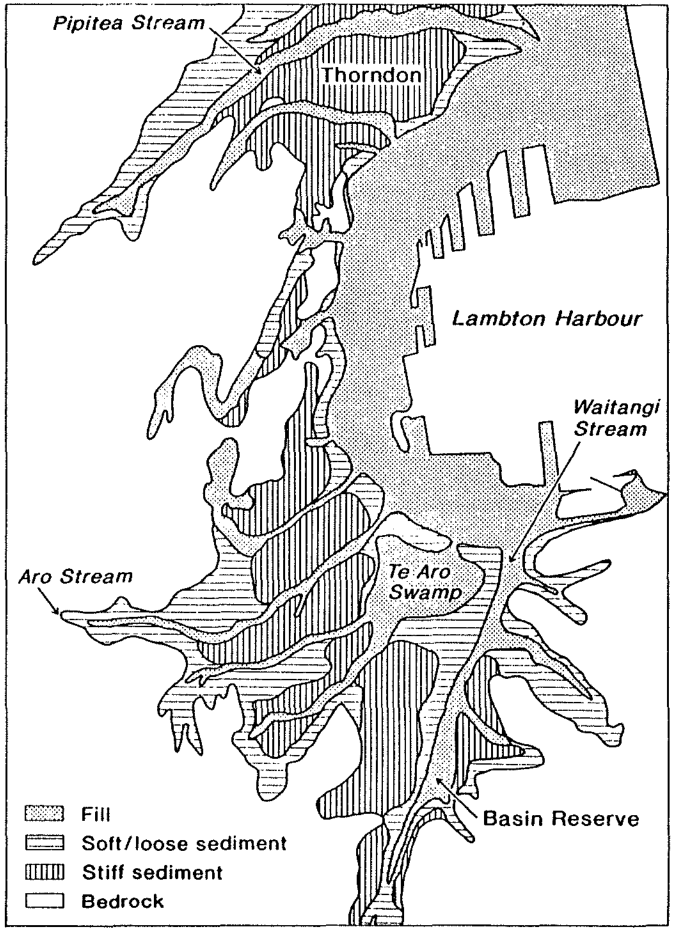

Figure 4: Sediment distribution in Wellington central city area. (After Perrin and Campbell, 1992).

- * The distribution of surface sediment types (Figure 4).
- * The thickness of near-surface soft and/or loose sediment (Figure 5).
- * The total sediment thickness to bedrock.

The maps provide the geological base for the ground shaking hazard zones.

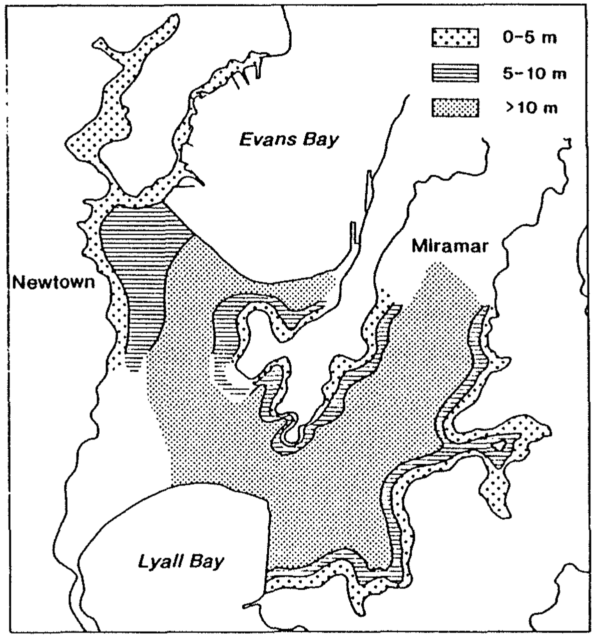

Figure 5: Soft sediment thicknesses in the Miramar-Kilbirnie area. (After Perrin and Campbell, 1992).

2.3.2 Weak ground motions

The microearthquake recording sites sampled a variety of geological ground conditions, ranging from bedrock to thick, soft, fine-grained marine sediment.

The relative shaking response of each site was expressed as an averaged ratio of the Fourier spectra of the seismograms compared to a reference bedrock site. The six bedrock sites had peak Fourier spectral ratios (FSR) of less than 1.7. Sites showing the highest amplifications of earthquake ground motions, relative to the reference bedrock site, were located adjacent to Lambton Harbour, in Miramar, Te Aro, Kent Terrace, Seatoun, the airport and part of Wellington Hospital. These sites had high to very high peak amplifications (FSR = 5.1 to 6.6), and with the exception of Seatoun, were underlain by more than 10 metres of soft and/or loose material. Nine of the weak motion sites were located on firm material (compact gravel and/or stiff to hard clay). These sites had low to moderate amplifications of earthquake ground motions (FSR = 1.6 to 3.3). The remaining four sites were underlain by 5 to 10 metres of soft and/or loose material, and showed moderate to high amplifications (FSR = 2.7 to 4.5).

2.3.3 **Penetrometer probings**

The nature of the near-surface material at several of the highest amplification sites was further defined using cone penetrometer and seismic-cone penetrometer probing (Figure 6). In Miramar the probe reached 7 metres before refusal, the result of accumulated side friction rather than high tip resistance. Using the seismic probe a shear wave velocity of 200 metres/second was measured for the upper 5 metres. The probe site in the grounds of Wellington Hospital reached 10 metres before refusal. Much of the material encountered was low strength with a shear wave velocity of 122 to 224 metres/second. In Te Aro (Jacobs Place) probing revealed at least 6 metres of material (fill, gravel and soft *flexible* sediment) with a shear wave velocity between 125 to 150 metres/second. The probes refusal at 6.2 metres may have been the result of a gravel layer, rather than the base of the deepest soft *flexible* layer.

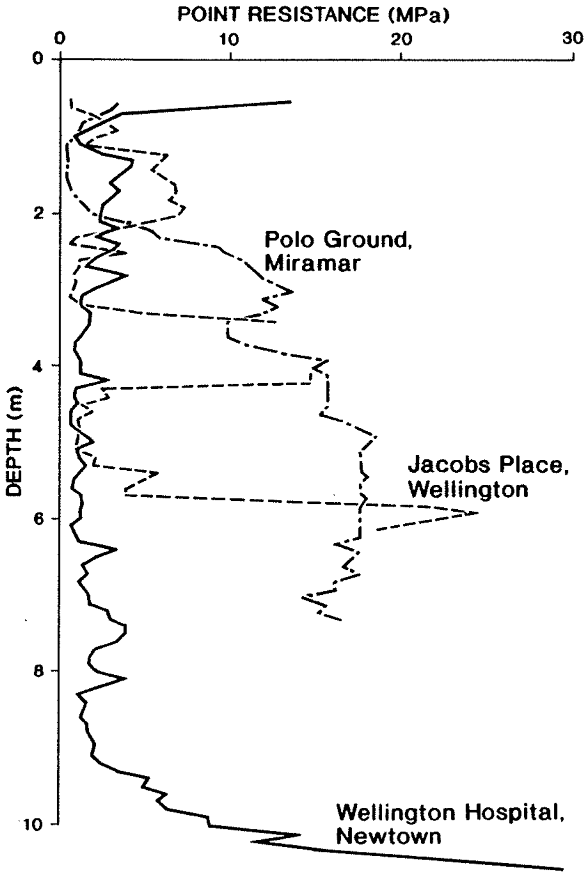

Figure 6: Cone penetrometer test results at three sites in Wellington City area. (After Stephenson and Barker, 1992).

2.3.4 **Ground shaking hazard zones**

Based on the distribution of geological materials and the measured response of these materials to seismic waves the Wellington study area was mapped into four ground shaking hazard zones; Zone 1, Zone 2, Zone 3-4, and Zone 5 (refer to accompanying map sheet).

Zone 1, the least hazardous zone, is characteristically underlain by bedrock and typically shows very low to low amplification of seismic waves.

Zone 2 areas are underlain by firm material, including compact gravel and stiff to hard clay or less than 5 metres of soft and/or loose material, and show low to moderate amplification of earthquake shaking, relative to bedrock.

Zone 3-4 represents a transition zone between the low to moderate amplification of ground shaking anticipated in Zone 2 and the high to very high amplification anticipated in Zone 5. Zone 3-4 areas are typically underlain by 5 to 10 metres of near surface soft and/or loose material, and are characterised by moderate to high amplification of earthquake ground motion relative to bedrock.

Zone 5 areas are underlain by more than 10 metres of soft and/or loose material. These materials generally have shear wave velocities in the order of 200 metres/second or less. Zone 5 areas are characterised by high to very high amplification of earthquake ground motion, relative to bedrock, and are therefore subject to the greatest ground shaking hazard.

Figure 7 illustrates some of the relationships between the ground shaking hazard zones and the geology.

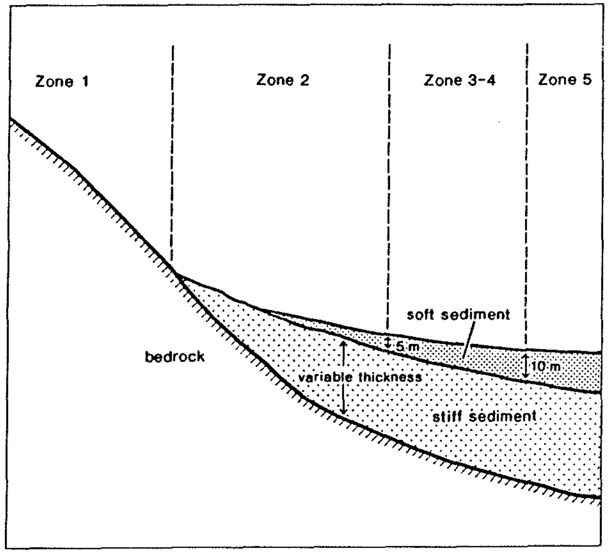

Figure 7: Diagrammatic cross section showing typical relationships between lithologies and ground shaking hazard zones. (After Van Dissen *et al*, 1992).

LITHOLOGY		DESCRIPTION	SPT N (Blows/300 mm)	SHEAR WAVE VELOCITY m/sec.
A	Fill	Loose rock fill, hydraulic fill	0 to 35 Typically 5	50 to 150
B	Loose	Sand/gravel/non-cohesive silt. Post-glacial.	5 to 60 Typically 20	150 to 200
Bb	Beach	Sand/silt/gravel with shells. Post-glacial.	Predominantly 5 May be up to 35 where gravelly	100 to 200
C	Soft	Clay/cohesive silt/peat. Post-glacial.	5 to 40 but typically 10	100 to 200
D	Stiff	Clay/silt with gravel. Organic layers present, also dense gravel. Pleistocene.	Main range 30 to 70, with soft layers <2 m thick to N=10	200 to 500
E	Bedrock	CW sandy silt/clay HW weak gravel MW mod. hard rock SW-UW hard rock	5 to 150 >150 >150 >150	Approximately 500 500 to 750 750 to 1000 1000 to 2000

Table 1: Summary physical properties of lithologies.

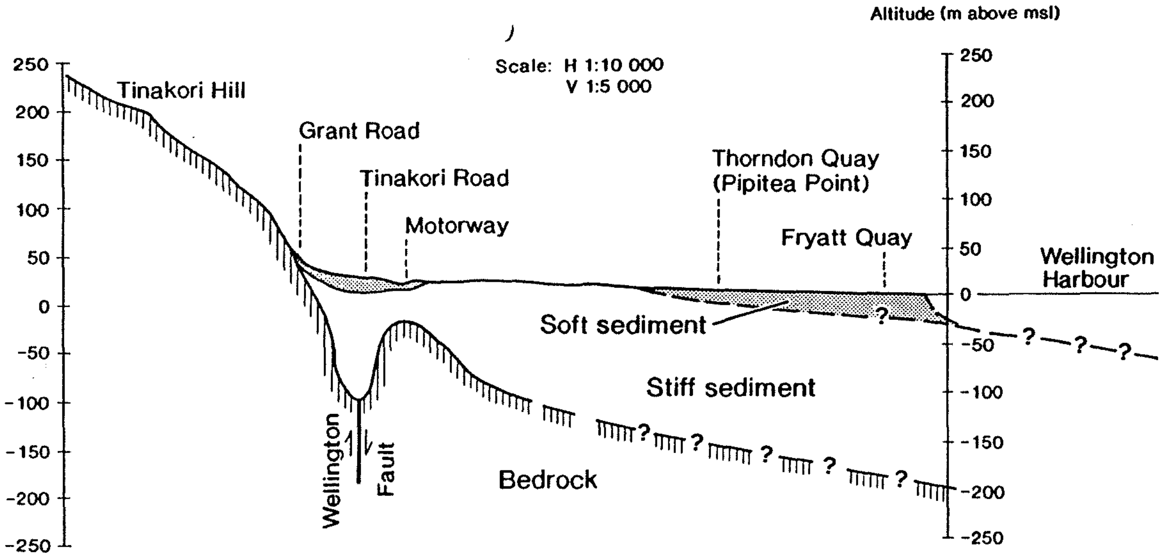

Figure 8: Geological cross section through Wellington City area. (After Perrin and Campbell, 1992).

2.4 GEOLOGICAL DESCRIPTION OF HAZARD ZONES

Descriptions of the geological materials that typify each hazard zone are given in Appendix 4. A summary of some of the physical properties of the geological materials is given in Table 1. Figure 8 shows the subsurface distribution of materials between Tinakori Hill and Fryatt Quay.

2.5 QUANTIFICATION OF HAZARD ZONES

The shaking response of the ground shaking hazard zones was assessed for the two earthquake scenarios (as described in Part 2.2). The response of each zone was expressed as a set of ground motion parameters, comprising:

- Expected Modified Mercalli intensity.
- Peak horizontal ground acceleration.
- Duration of strong shaking.
- Amplification of ground motion with respect to bedrock - expressed as a Fourier spectral ratio.

Some of these parameters were measured directly, others were estimated using comparisons found in the published scientific and engineering literature.

The Loma Prieta earthquake (1989, San Francisco) is significant to this study because of the recorded variations in ground motion related to local geological conditions and because the magnitude is similar to that expected for the Scenario 1 earthquake. Therefore, the values calculated for the ground motion parameters used in this study were compared with those measured for the Loma Prieta event.

2.5.1 Modified Mercalli intensity

Scenario 1: The Scenario 1 earthquake (a large, distant, shallow earthquake, resulting in MM V-VI shaking on bedrock) will be of sufficient duration and contain sufficient long period energy to allow strong long-period response to develop at deeper sediment sites. The shallow focal depth will allow strong surface wave effects. The result will be a marked difference between the shaking of the *worst* sediment site and the *best* firm site. It is not uncommon during an earthquake to have a spread of three to four units of MM intensity separating the response of the *best* site from the response of a nearby *worst* site. A difference of three to four MM units is therefore expected between the response of Zone 1 and Zone 5. The response of Zones 2 and 3-4 is expected to be slightly stronger than Zone 1.

Scenario 1

Zones	**MM Intensity**	**Peak Ground Acceleration (g)**	**Duration**	**Amplification of Ground Motion (FSR)**
1	V-VI	0.02-0.06	< 5 sec.	< 2x
2	VI	0.02-0.1	2-3x	1.5-3.5x
3-4	VI-VII	0.02-0.1	2-3x	2.5-5x
5	VIII-IX	< 0.3 generally between 0.1-0.2	> 3x	> 5x*

Scenario 2

Zones	**MM Intensity**	**Peak Ground Acceleration (g)**	**Duration**
1	IX	0.5-0.8	15-40 sec.
2	IX-X	0.5-0.8	1-2x
3-4	IX-X	0.5-0.8	1-2x
5	X-XI	0.6-0.8	> 2x

* Peak amplifications at most sites within Zone 5 occurred within a narrow frequency band between 1-2Hz.

Table 2: Ground motion parameters for the ground shaking hazard zones in the Wellington area.

In terms of MM intensity the response of Zone 1 is expected to be MM V with some VI, Zone 2 is MM VI, Zone 3-4 is MM VI-VII and Zone 5 is MM VII-IX (Table 2).

Scenario 2: The effects of a Scenario 2 event (a large, local Wellington Fault earthquake) will be a marked increase in the shaking throughout the study area, relative to Scenario 1, a decrease in the average difference in shaking between Zone 1 and Zone 5, and an increase in the variability of shaking within each zone.

An important factor influencing ground shaking for a Scenario 2 event is distance from the earthquake source. In general, shaking decreases with increased distance from the source. However, the entire Wellington study area is within 8 kilometres

SCENARIO 1 EARTHQUAKE	
Hazard Zones	**Ground conditions and likely effects**
1	**"Greywacke"/Argillite Bedrock** : Little ground damage. Small (<100 m^3) local failures on steep slopes and unsupported cut batters. Small local failures on cuts in weathered gravels.
2	**Alluvial Deposits** : Little or no significant damage likely. Small local failures on river banks possible.
3-4	**Thicker Alluvial Deposits** : Little widespread damage expected. Small localised failures of banks adjacent to rivers, streams, or cuts. Some local cracking and sand ejection possible at MM VII.
5	**Soft Sediments** : Widespread minor slumping of steep banks (>2 m high). Localised lateral spreading of ground adjacent to river and stream banks with sand ejection (liquefaction effects). Differential settlement and collapse possible in some areas - especially in areas where the water table is close to the ground surface and adjacent to river banks.
SCENARIO 2 EARTHQUAKE	
Hazard Zones	**Ground conditions and likely effects**
1	**"Greywacke" Bedrock** : Small failures of bedrock and surficial deposits. Widespread on steep slopes and on steep unsupported cuts (>2 m high).
2	**Alluvial Deposits** : Only little significant ground damage expected. Small localised failures of river banks and cuts. Cracking and lateral spreading likely adjacent to river and stream channels with sand ejection due to liquefaction. Minor settlement and collapse of saturated materials in most places.
3-4	
5	**Soft Sediments** : Effects as for Zones 2 and 3-4 - except that damage will be widespread, and at a greater scale. Liquefaction effects (sand ejection, cracking, lateral spreading and settlement) would be widespread, and seriously damaging in some places, especially areas adjacent to river and stream courses.

Table 3: Ground damage effects likely in each ground shaking hazard zone for the two earthquake scenarios.

of the surface trace of the Wellington Fault. Therefore, distance from the Fault is not expected to be a dominant factor in determining the relative levels of shaking within the study area.

Epicentral intensities for the 1989 Loma Prieta earthquake were MM VIII. However, the Loma Prieta earthquake was smaller than the Scenario 2 event (M 7.1 compared to M 7.5). Epicentral intensities for similarly sized New Zealand earthquakes have been MM IX (1848 Marlborough), MM IX-X (1931 Hawkes Bay) and MM VIII-IX (1968 Inangahua).

On the basis of these relationships, MM IX is expected in Zone 1. In both Zones 2 and 3-4 the response is expected to be MM IX-X. Violent shaking, MM X-XI, is expected in Zone 5 (Table 2).

Some of the possible ground damage effects that are likely in the various hazard zones for the two earthquake scenarios are given in Table 3. These are based largely on the expected MM intensities, as well as knowledge of earlier damaging earthquakes in the Wellington Region and elsewhere.

2.5.2 Peak horizontal ground acceleration

Scenario 1: Peak ground acceleration for Zone 1 is expected to be in the order of 0.02 to 0.06g. This compares to the 0.06g recorded during the Loma Prieta earthquake at a hard rock site 95 kilometres from the epicentre. Accelerations of 0.02 to 0.1g are expected in Zones 2 and 3-4. For Zone 5, average accelerations of 0.1 to 0.2g are expected. Accelerations could be as high as 0.3g, based on the 0.29g acceleration recorded 97 kilometres from the Loma Prieta epicentre on a *soil site*. Strong long period response is also anticipated for the deepest sediment sites within the study area.

Scenario 2: The average peak ground accelerations expected for Scenario 2, based on a variety of attenuation relations and geological site considerations, are as follows: Zone 1, 0.5 to 0.8g; Zone 2, 0.5 to 0.8g; Zone 3-4, 0.5 to 0.8g and Zone 5, 0.6 to 0.8g.

2.5.3 **Duration of strong shaking**

Duration provides a qualitative estimate of the effects that local geological deposits can have in increasing the length of time a site will experience strong shaking. In general, amplitudes and durations of shaking increase with decreasing firmness of the underlying sediment. This has been observed in the Wellington area for non-damaging earthquakes and elsewhere for larger damaging earthquakes. In this study *duration* refers to the time between the first and last accelerations that exceed 0.05g.

Scenario 1: The expected duration of strong shaking in Zone 1 during a Scenario 1 event is less than 5 seconds (Table 2). The expected increase in duration, relative to bedrock, is 2 to 3 times in Zone 2 and Zone 3-4, and more than 3 times in Zone 5.

Scenario 2: Length of fault rupture is a controlling factor regarding the duration of near-source ground shaking. The Loma Prieta earthquake produced about 10 seconds of strong shaking, resulting from a 40 kilometres bilateral rupture (rupture propagation from the centre of the fault to the ends). Had the rupture been unilateral (rupture propagation from one end of the fault) the shaking would have lasted much longer, perhaps up to 20 seconds. Rupture of the Wellington Fault in Scenario 2 is expected to be about twice as long as the rupture that produced the Loma Prieta earthquake. The duration of shaking for Zone 1 during Scenario 2 is expected to be 15 to 40 seconds, by comparison with the Loma Prieta event and depending on whether the rupture propagates bilaterally or unilaterally. The increase in duration, relative to Zone 1, is 1 to 2 times for Zone 2 and Zone 3-4, and greater than 2 times for Zone 5 (Table 2).

2.5.4 **Amplification of ground motion spectrum**

Characteristic peak Fourier spectral ratios, within the frequency band of 0.5 to 4 Hz, are summarised in Table 2. The results are useful for determining relative shaking and for identifying the frequencies over which this shaking will be most strongly amplified during certain earthquakes, specifically Scenario 1 type events.

Ground motion amplification at most of the sites in Wellington occurs over a broad frequency band. However, some sites, particularly those in Zone 5, exhibit a narrow (resonant) frequency response. Site resonance is of most concern where built structures have natural periods that coincide with the resonant period band(s) of strong ground shaking. All Zone 5 sites had peak amplifications within a narrow (less than 2 Hz wide) frequency band. The maximum occurs in the range from 1 to 2 Hz, except for Kent Terrace and Wellington Hospital where maxima occur at 2.5 and 4 Hz respectively. Seatoun is also noted for its amplified (FSR greater than 4) high frequency response between 5 to 12 Hz.

Even though the ground motion amplifications measured in Wellington were recorded during non-damaging earthquakes it is significant to note that intensity maps, prepared in the 1970's for the San Francisco Bay area, anticipated all of the areas that experienced high intensity shaking during the 1989 Loma Prieta earthquake. The level of amplification during even larger ground motions at near-source sites is unresolved. An amplification of FSR greater than 5 is unlikely to persist to extreme motions. This is because at high strain levels weak sediments begin to behave in a non-linear fashion - they begin to lose strength and increase wave attenuation or damping. Nevertheless, variations in the nature of seismic response can still be expected from one zone to another. High amplification of small bedrock ground motions, such as the Scenario 1 bedrock motions, means that significant local damage in Zone 5 could result from an earthquake that would cause little or no damage in Zone 1. Amplification of small bedrock ground motions are best characterised by measured spectral ratios and are therefore given only for Scenario 1.

3. ASSUMPTIONS AND LIMITATIONS

Important assumptions that limit the certainty with which the ground shaking hazard zones can either be mapped or quantified are discussed below.

(1) Within each hazard zone there are isolated occurrences of materials that may cause ground motions that are not typical of the zone as a whole. For example, it is unclear whether infilled channels in the Willis Street/Cuba Street area (mapped as Zone 3-4) are extensive enough to result in the moderate to high amplifications anticipated in Zone 3-4. A conservative approach was adopted.

Significant variations in amplified resonant response over relatively short distances in some areas, for example Te Aro, emphasise the importance of site specific studies to determine the nature and response of the materials at a site.

(2) The distribution of materials causing high amplifications is not well defined in some areas. The poorly resolved boundary around the Zone 5 areas is denoted as a *dot-dash* line on the ground shaking hazard map.

(3) Near-surface shear wave velocities, including velocity profiles, for the geological materials in the Wellington study area are not well known. Shear wave velocity is the parameter that best correlates with site amplification.

(4) Amplification of ground motion due to topographic effects has not been addressed for this study. Though probably localised, these effects can be pronounced.

(5) There is a marked directionality in the response at some strong motion sites at select frequencies. It is unclear whether this directionality is consistent in different earthquakes.

(6) The ground damage effects given in Table 3 are estimated from a general knowledge of past earthquakes in the Wellington Region and elsewhere, and have not been the subject of detailed study.

(7) Scenario 2 ground motion parameters are defined with less certainty. There is a worldwide lack of near-source ground motion data recorded during large earthquakes. During a large local earthquake near-source seismic wave propagation will be complex and non-uniform, and ground strains will be large enough to cause some sediments to exhibit non-linear response. These effects will tend to increase the variability of shaking within a zone, decrease the average difference in shaking between zones and decrease the certainty with which expected ground motions can be characterised. Also, near-source ground motions for an earthquake associated with a long fault rupture, such as Scenario 2, may be correlated with proximity to local asperities along the fault rupture, rather than proximity to the fault itself.

(8) The information given in this booklet and on the accompanying map is the result of a regional scale multi-disciplinary study of ground shaking hazard. The booklet and map provide useful information for the mitigation of ground shaking hazard in the Wellington study area but should not be used to replace site specific studies.

Detailed geological mapping, additional penetrometer probing, seismograph instrumentation, and topographic and mathematical modelling would resolve some of these issues.

4. SUMMARY

The geographic variation in ground shaking was defined using information from drillhole logs, microearthquake records, strong motion earthquake records and penetrometer logs. Four ground shaking hazard zone were established . These are Zone 1, Zone 2, Zone 3-4 and Zone 5. The geographic distribution of the zones is shown on the accompanying map.

Zone 1 areas are the least hazardous and are underlain by bedrock. Zone 2 areas show low to moderate amplification of earthquake shaking and are underlain by firm material. Zone 3-4 areas show moderate to high amplification of earthquake motions and are typically underlain by 5 to 10 metres of near-surface soft and/or loose material. Zone 5 areas show high to very high amplification of earthquake motion and are underlain by more than 10 metres of soft and/or loose material.

The expected response of each ground shaking hazard zone to two earthquake scenarios is given by Modified Mercalli intensity, peak ground acceleration, duration and amplification of ground motion parameters. The two parameters most easily understood are MM intensity and duration. For a large distant earthquake (Scenario 1) MM values range from V-VI in Zone 1, to VIII-IX in Zone 5. The response will range from *some alarm and damage* in Zone 1 areas to *general panic and substantial damage* in Zone 5 areas. Strong shaking will last for less than 5 seconds in Zone 1 areas, but continue for more than 15 seconds in Zone 5 areas. For a large earthquake centred on the Wellington Fault (Scenario 2) there is less difference between the zones, with strong shaking experienced everywhere. However, Zone 5 areas are expected to shake strongly for twice the duration of Zone 1 sites and to experience MM intensity 1 to 2 units higher on the scale.

Important assumptions that limit the certainty with which the ground shaking hazard zones can either be mapped or quantified must be considered when interpreting the hazard information.

APPENDICES

APPENDIX 1: CONTRIBUTING REPORTS AND REFERENCES

Hastie W J (1992). Seismic hazard: Summary report on work carried out in 1991/92. Publication No. WRC/PP-T-92/23, Policy and Planning Department, Wellington Regional Council.

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APPENDIX 2: GLOSSARY OF TECHNICAL TERMS

Active fault: A fault with evidence of surface movement in the last 50000 years or repeated surface movement in the last 500000 years.

g: Gravity. For an earthquake which produces a ground acceleration of 0.4g the actual acceleration is 40 percent of gravity.

Hazard: A potentially damaging physical event.

Liquefaction: Process by which water-saturated sediment temporarily loses strength, usually because of strong shaking, and behaves as a fluid.

Quaternary: Geological time period spanning the last 2 million years.

Risk: The combination of a natural hazard event and our vulnerability to it. Risk can be specified in terms of expected number of lives lost, persons injured, damage to property, and disruption of economic activity due to a particular natural hazard.

Seiche: Oscillation of the surface of an enclosed body of water owing to earthquake shaking.

Seismic: To do with earthquake or earthquake-like motions in the earth.

Tsunami: An impulsively generated sea wave of local or distant origin that results from seafloor fault movement, large scale seafloor slides, or volcanic eruption on the seafloor.

APPENDIX 3: MODIFIED MERCALLI INTENSITY SCALE

MM 1: Not felt by humans, except in especially favourable circumstances, but birds and animals may be disturbed. Reported mainly from the upper floor of buildings more than 10 storeys high. Dizziness or nausea may be experienced. Branches of trees, chandeliers, doors and other suspended systems of long natural period may be seen to move slowly. Water in ponds, lakes and reservoirs may be set into seiche oscillation.

MM II: Felt by few a persons at rest indoors, especially by those on upper floors or otherwise favourably placed. The long period effects listed under MM I may be more noticeable.

MM III: Felt indoors but not identified as an earthquake by everyone. Vibration may be likened to the passing of light traffic. It may be possible to estimate the duration but not the direction. Hanging objects may swing slightly. Standing motorcars may rock slightly.

MM IV: Generally noticed indoors, but not outside. Very light sleepers may be wakened. Vibration may be likened to the passing of heavy traffic, or to the jolt of a heavy object falling or striking the building. Walls and frames of buildings are heard to creak. Doors and windows rattle. Glassware and crockery rattle. Liquids in open vessels may be slightly disturbed. Standing motorcars may rock and the shock can be felt by their occupants.

MM V Generally felt outside and by almost everyone indoors. Most sleepers awakened. A few people frightened. Direction of motion can be estimated. Small unstable objects are displaced or upset. Some glassware and crockery may be broken. Some windows cracked. A few earthenware toilet fixtures cracked. Hanging pictures move. Doors and shutters may swing. Pendulum clocks stop, start or change rate.

MM VI: Felt by all. People and animals alarmed. Many run outside. Difficulty experienced in walking steadily. Slight damage to Masonry D. Some plaster cracks or falls. Isolated cases of chimney damage. Windows, glassware and crockery broken. Objects fall from shelves and pictures from walls. Heavy furniture overturned. Small church and school bells ring. Trees and bushes shake, or are heard to rustle. Loose material may be dislodged from existing slips, talus slopes, or shingle slides.

MM VII: General alarm. Difficulty experienced in standing. Noticed by drivers of motorcars. Trees and bushes strongly shaken. Large bells ring. Masonry D cracked and damaged. A few instances of damage to Masonry C. Loose brickwork and tiles dislodged. Unbraced parapets and architectural ornaments may fall. Stone walls cracked. Weak chimneys broken, usually at the roofline. Domestic water tanks burst. Concrete irrigation ditches damaged. Waves seen on ponds and lakes. Water made turbid by stirred-up mud. Small slips and caving in of sand and gravel banks.

MM VIII: Alarm may approach panic. Steering of motorcars affected. Masonry C damaged, with partial collapse. Masonry B damaged in some cases. Masonry A undamaged. Chimneys, factory stacks, monuments, towers and elevated tanks twisted or brought down. Panel walls thrown out of frame structures. Some brick veneers damaged. Decayed wooden piles broken. Frame houses not secured to the foundations may move. Cracks appear on steep slopes and in wet ground. Landslips in roadside cuttings and unsupported excavations. Some tree branches may be broken off. Changes in the flow or temperature of springs and wells may occur. Small earthquake fountains may form.

MM IX: General panic. Masonry D destroyed. Masonry C heavily damaged, sometimes collapsing completely. Masonry B seriously damaged. Frame structures racked and distorted. Damage to foundations general. Frame houses not secured to the foundations shifted off. Brick veneers fall and expose frames. Cracking of the ground conspicuous. Minor damage to paths and roadways. Sand and mud ejected in alleviated areas, with the formation of earthquake fountains and sand craters. Underground pipes broken. Serious damage to reservoirs.

MM X: Most masonry structures destroyed, together with their foundations. Some well built wooden buildings and bridges seriously damaged. Dams, dykes and embankments seriously damaged. Railway lines slightly bent. Cement and asphalt roads and pavements badly cracked or thrown into waves. Large landslides on river banks and steep coasts. Sand and mud on beaches and flat land moved horizontally. Large and spectacular sand and mud fountains. Water from rivers, lakes and canals thrown up on banks.

MM XI: Wooden frame structures destroyed. Great damage to railway lines and underground pipes.

MM XII: Damage virtually total. Practically all works of construction destroyed or greatly damaged. Large rock masses displaced. Lines of sight and level distorted. Visible wave-motion of the ground surface reported. Objects thrown upwards into the air.

APPENDIX 4: GEOLOGICAL DESCRIPTIONS OF HAZARD ZONES

Zone 1: Bedrock. Moderately to very strong sandstone and siltstone (argillite), collectively referred to as *Greywacke*, also includes areas where bedrock is overlain by less than 10 metres of deeply weathered gravel and loess or well engineered fill.

Zone 2: Stiff Sediment. Compact to very compact granular material, and stiff to hard clay (completely weathered bedrock), up to a thickness of about 120 metres. Materials in this zone typically have Standard Penetration Test (SPT) values in the range of 30 to 70, and are primarily composed of Pleistocene gravel, including periglacial deposits, and stream and fan alluvium. The coarser deposits are often interfingered with beds and lenses of finer grained sediment (sand, silt, clay and peat) usually less than 5 metres thick. Areas where fine-grained sediment is present at the surface are also mapped as Zone 2 when the thickness of fine-grained sediment is less than 5 metres.

Zone 3-4: Transition Zone Between Zone 2 and Zone 5. Non-bedrock areas that are not mapped as Zone 2 and are underlain by less than 10 metres of near-surface soft and/or loose sediment. Zone 3-4 areas are typically underlain by 5 to 10 metres of near surface soft and/or loose sediment and a variable thickness, up to about 150 metres, of stiff sediment.

Zone 5: Soft and Loose Sediment. More than 10 metres of near-surface fine-grained, cohesive, soft sediment, or coarse-grained, non-cohesive loose to medium dense sediment. These materials comprise Holocene (less than 10000 years old) marine, terrestrial, and stream deposits, underlain by bedrock or a variable thickness, up to about 150 metres, of stiff sediment. Zone 5 materials have SPT values in the order of 10, ranging from 5 to 40 and shear wave velocities of 125 to 225 metres/second.

GROUND SHAKING HAZARD
PORIRUA

NOTES TO ACCOMPANY

SEISMIC HAZARD MAP SERIES: GROUND SHAKING HAZARD MAP SHEET 2 PORIRUA (FIRST EDITION) 1:25000

OCTOBER 1992

Publication WRC/PP-T-92/46

Compiled by

P A Kingsbury and W J Hastie

POLICY AND PLANNING DEPARTMENT

1. INTRODUCTION

1.1 BACKGROUND

The occurrence of earthquakes in the Wellington Region is inevitable due to its location at the boundary of two crustal plates. Earthquakes have the potential to cause significant adverse effects within the Region, including loss of life, injury, and social and economic disruption. In recognition of these potential effects the Wellington Regional Council initiated a project in 1988 to:

* Assess the risks posed by earthquakes.
* Identify mitigation options.
* Implement measures to ensure that the level of risk is acceptable.

The first step in the project is to define the characteristics of the hazard. Information on the type and magnitude of possible effects, the probability of these occurring and the location of the effects within the Region is required. For the purposes of the project *earthquake hazard* has been divided into a number of separate but interrelated components, including:

* Ground shaking.
* Surface fault rupture.
* Liquefaction and ground damage.
* Landsliding.
* Tsunami.

Although not all the effects will occur during every earthquake, and many will be localised, all components must be considered to obtain a complete picture of earthquake hazard.

1.2 PURPOSE OF MAP AND BOOKLET

A series of six map sheets, with accompanying booklets, have been compiled to describe the *ground shaking hazard* for the main metropolitan areas in the Region (refer to Index Map on accompanying map sheet):

* Sheet 1 - Wellington.
* Sheet 2 - Porirua and Tawa.
* Sheet 3 - Lower Hutt.
* Sheet 4 - Upper Hutt.
* Sheet 5 - Paekakariki, Paraparaumu, Waikanae and Otaki.
* Sheet 6 - Featherston, Greytown, Carterton and Masterton.

The purpose of the maps is to show the geographic variation in ground shaking hazard that could be expected during certain earthquake events. The map sheets and booklets have been compiled from Wellington Regional Council reports and detailed reports prepared for the Wellington Regional Council by DSIR Geology and Geophysics, Land Resources and Physical Sciences, and Victoria University of Wellington. A list of the reports is given in Appendix 1.

The intention of the map and booklet series is to raise public awareness of ground shaking hazard in the Wellington Region. The information should be useful to a range of potential users, including land use planners, civil defence organisations, land developers, engineers, utility operators, scientists and the general public.

Information on active faults in the western part of the Region has been published in a map series by the Wellington Regional Council - *Major Active Faults of the Wellington Region* (Map sheets 1, 2 and 3: 1991). Tsunami hazard information for Wellington Harbour is also available.

1.3 BOOKLET STRUCTURE

This booklet is divided into four main parts. Part 1 provides background information on the study. Part 2 outlines the hazard assessment approach and details the mapping methodology. Parameters used to quantify the hazard zones are also discussed. Part 3 states the assumptions and limitations that determine the certainty with which the hazard zones can either be mapped or quantified. A brief summary is given in Part 4.

Technical terms are defined in Appendix 2.

2. HAZARD ASSESSMENT

2.1 DATA SOURCES

The geographic variation in earthquake ground shaking was defined using geological and geotechnical information from drillhole records, seismic refraction surveys, microearthquake records and penetrometer logs. Numerical techniques to model the seismic response of soft *flexible* sediments in Porirua were also used. An array of 12 digital seismographs were used to measure the response of various geological materials during microearthquakes.

2.2. EARTHQUAKE SCENARIOS

The Wellington Region is located across the boundary of the Pacific and Australian plates (Figure 1). As a consequence, the Region is cut by four major active faults, and is frequently shaken by moderate to large earthquakes (Figures 2 and 3).

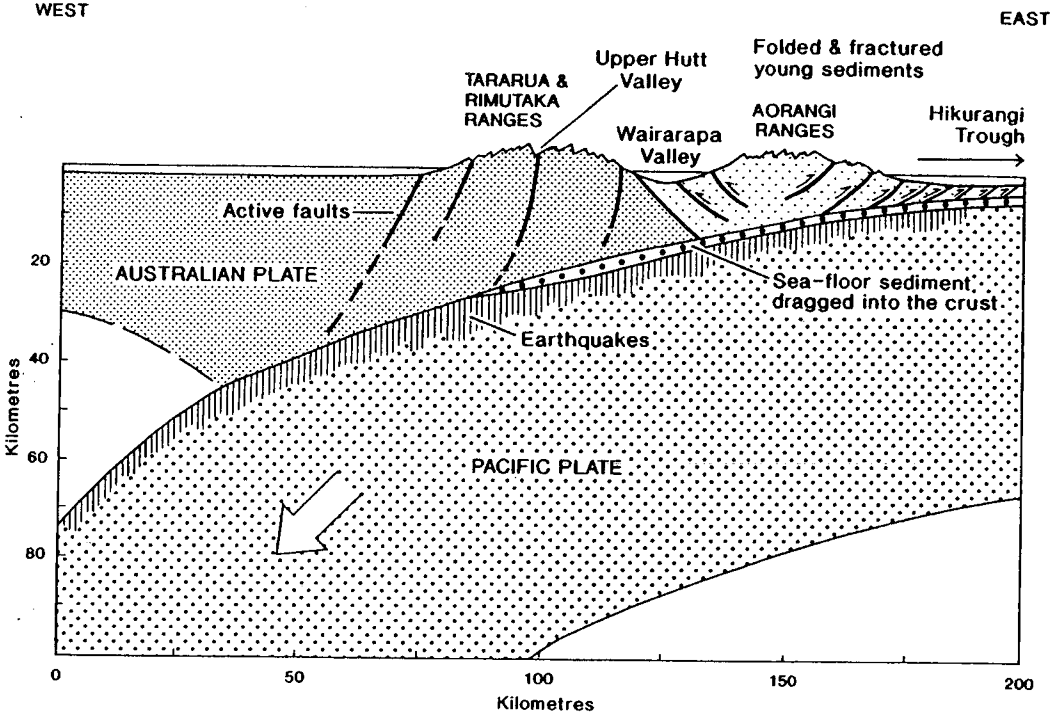

Figure 1: Source of earthquakes at plate boundary and along active faults (After Stevens, 1991)

Because no single earthquake event adequately describes the potential ground shaking hazard in the Region, two earthquake scenarios were used to define the hazard.

Scenario 1 is for a large, distant, shallow earthquake that produces Modified Mercalli intensity (MM) V-VI on bedrock (Appendix 3). It is expected that this type of earthquake will produce the largest variation in ground response. Scenario 1 implies minor damage to structures founded on the *best* sites and significant damage to certain structures on the *worst* sites. An example of such an event would be a Magnitude (M) 7 earthquake centred about 100 kilometres from the study area at a depth of less than 30 kilometres. Twenty years is a minimum estimate for the return time of a Scenario 1 event. This return time is derived from the historical occurrence of both large earthquakes and moderate sized local events. A maximum estimate is 80 years, which is the return time of MM VII or greater shaking at bedrock sites in the Wellington Region.

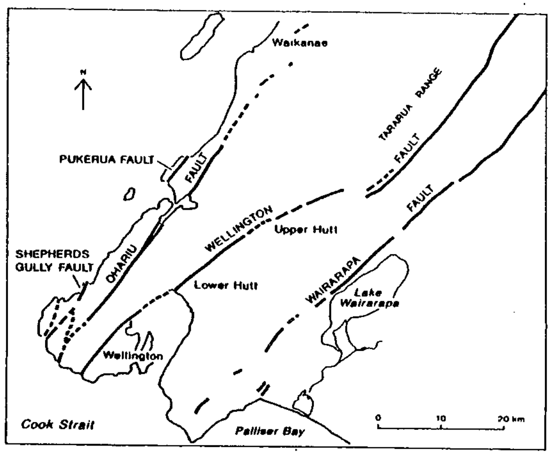

Figure 2: Active faults in the western part of the Wellington Region.

Scenario 2 is for a large earthquake centred on the Wellington-Hutt Valley segment of the Wellington Fault. Rupture of this segment is expected to be associated with a Magnitude 7.5 earthquake at a depth less than 30 kilometres, and up to 5 metres of horizontal and 1 metre vertical displacement at the ground surface. The return time for such an event is about 600 years and the probability of this event occurring in the next 30 years is estimated to be 10 percent. The values for near-source shaking resulting from a Scenario 2 earthquake are given with less certainty. This is because there are so few near-source ground motion data from large earthquakes, and factors such as proximity to local asperities along the rupture plane and random cancellation and reinforcement of seismic waves can locally suppress the effects caused by near-surface geological deposits. Furthermore, amplification of some local geological deposits will

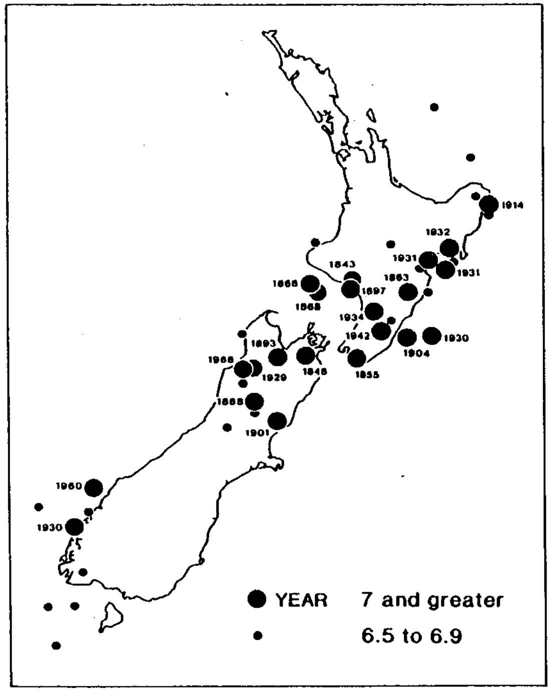

Figure 3: Epicentres of shallow earthquakes of magnitude 6.5 and greater since 1840 (After Van Dissen, 1991).

not occur at particular ground shaking frequencies and strengths.

2.3 MAPPING METHODOLOGY

2.3.1 Surface geology

The surface geology of the Porirua area was mapped using nine units:

- Fill.
- Swamp.
- Alluvial gravels and small alluvial fans.
- Marine silt, sand and estuarine peat.
- Windblown sand.

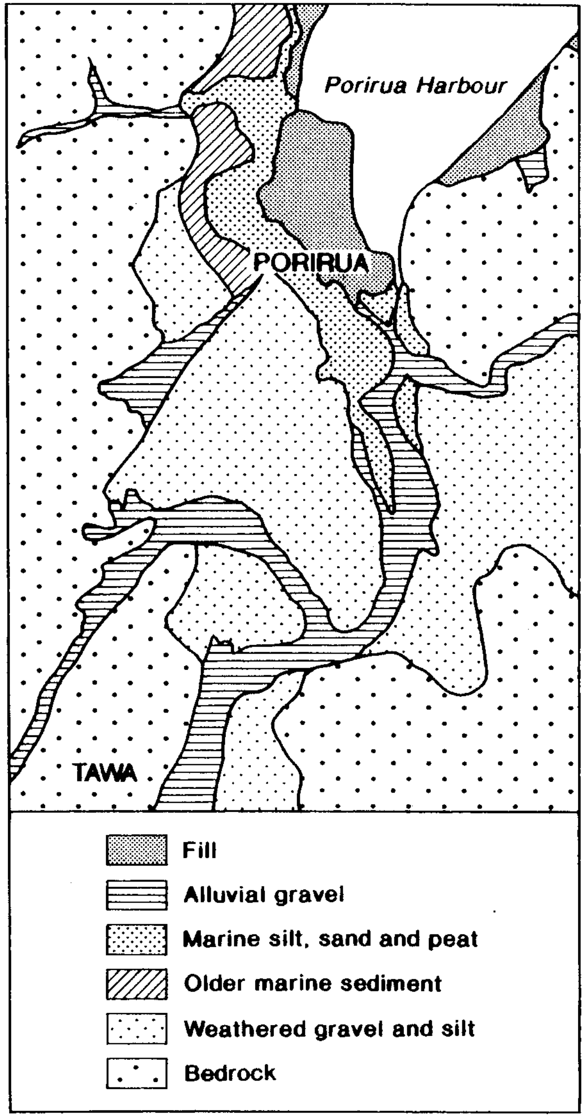

Figure 4: Surface geology deposits in the Poriura-Tawa area.

- Older marine silt, sand and fine gravel.
- Older alluvial silt, sand and gravel.
- Deeply weathered sandy gravel and silt.
- Bedrock (Torlesse Supergroup Greywacke).

The distribution of surface geology deposits between Porirua and Tawa is shown in Figure 4. Subsurface geology was interpreted from drillholes, standard penetration tests (SPT), cone penetrometer tests (CPT) and seismic refraction surveys.

The geology information provided the base for the ground shaking hazard zones.

2.3.2 Weak ground motions

The microearthquake recording sites sampled a variety of geological ground conditions, ranging from bedrock to significantly thick soft *flexible* sediments.

The relative shaking response of each site was expressed as an averaged ratio of the Fourier spectra of the seismograms compared to a reference bedrock site. The recorded ground shaking at the *flexible* sediment sites was 10 to 20 times stronger than that of the reference bedrock site, and occurs over a narrow frequency band (1 to 3Hz). The ground response at firm sites, including bedrock sites and sites where bedrock is overlain by more than 10 metres of deeply weathered gravel and loess, was also measured. With the exception of one site, the spectral ratios for firm sites varied from no amplification to factors of about 3 relative to the hard rock reference site. The exception was a firm site on a small ridge in Whitby which showed a spectral ratio of nearly 10 at 5.5Hz. The amplification at this site could in part be due to topographic effects since spectral ratios of up to 8 have been recorded at hard ridge-crest sites. Cone penetrometer results discount the possibility of a significant thickness of soft sediment near this site.

2.3.3 **Penetrometer probings**

The nature of the near-surface material at several sites was further defined using cone penetrometer and seismic-cone penetrometer probing. The results of CPT investigations at Kura Park (Titahi Bay) are shown in Figure 5.

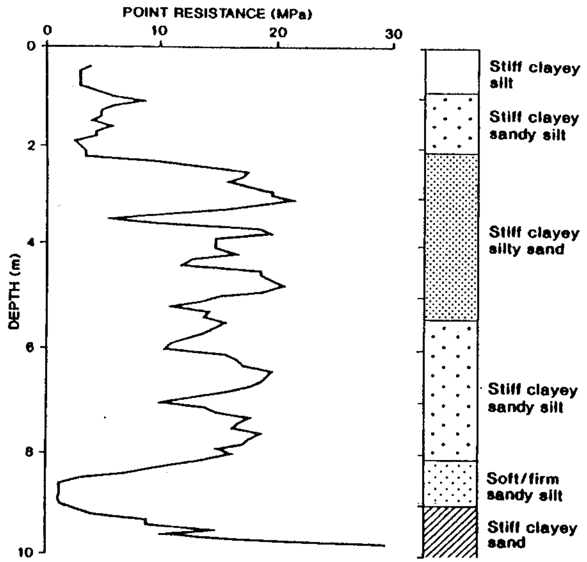

Figure 5: Cone penetrometer test results at Kura Park, Titahi Bay.

2.3.4 **Ground shaking hazard zones**

Based on the distribution of geological materials and the measured response of these materials to seismic waves the Porirua study area was mapped into three ground shaking hazard zones; Zone 1, Zone 2, and Zone 5 (refer to accompanying map sheet).

Zone 1, the least hazardous zone, is characteristically underlain by bedrock and typically shows very low to low amplification of seismic waves. Zone 2 is characterised by areas underlain by 10 metres or more of gravel and *compact* sand and only slight amplification of seismic waves. Areas underlain by a significant thickness (about 10 to 30 metres) of soft *flexible* sediment show greatly amplified shaking, and are mapped as Zone 5.

2.4 GEOLOGICAL DESCRIPTION OF HAZARD ZONES

Descriptions of the geological materials that typify each hazard zone are given in Appendix 4. A summary of some of the engineering properties of the geological materials is given in Table 1.

MATERIAL DESCRIPTION	ENGINEERING PROPERTIES			
	DRILLING/PROBING		LABORATORY TESTING	
	SPT (blows/300 mm)	CPT (cone res MPa)	Water Content (%)	Void Ratio (e)
PORIRUA ARM				
Soft Sediments (to 15 m depth)				
Silts and Sandy Silts	1-10	1-5	20-40	1.0-1.5
Sands (and gravelly sands)	10-20	5-10	40-60	0.6-1.0
Coarse Grained Alluvial Sediments				
Clayey Gravels	30-100	>30	Not tested	Not tested
Silty Sandy Gravels	15-30	>30	Not tested	Not tested
PAUAHATANUI ARM				
Soft Sediments	-	1-5	Not tested	Not tested
Gravels	-	>30	Not tested	Not tested
HARBOUR ENTRANCE				
Soft Sediments	-	-	Not tested	Not tested
Coarse Grained Alluvial Sediments	-	>30	Not tested	Not tested

Table 1: Summary of typical engineering properties for Quarternary age sediments in the Porirua area.

2.5 QUANTIFICATION OF HAZARD ZONES

The shaking response of the ground shaking hazard zones was assessed for the two earthquake scenarios (as described in Part 2.2). The response of each zone was expressed as a set of ground motion parameters, comprising:

- Expected Modified Mercalli intensity.
- Peak horizontal ground acceleration.
- Duration of strong shaking.
- Amplification of ground motion with respect to bedrock - expressed as a Fourier spectral ratio.

Some of these parameters were measured directly, others were estimated using comparisons found in the published scientific and engineering literature.

The Loma Prieta earthquake (1989, San Francisco) is significant to this study because of the recorded variations in ground motion related to local geological conditions and because the magnitude is similar to that expected for the Scenario 1 earthquake. Therefore, the values calculated for the ground motion parameters used in this study were compared with those measured for the Loma Prieta event.

2.5.1 Modified Mercalli intensity

Scenario 1: The Scenario 1 earthquake (a large, distant, shallow earthquake, resulting in MM V-VI shaking on bedrock) will be of sufficient duration and contain sufficient long period energy to allow strong long-period response to develop at deeper sediment sites. The shallow focal depth will allow strong surface wave effects. The result will be a marked difference between the shaking of the *worst* sediment site and the *best* firm site. It is not uncommon during an earthquake to have a spread of three to four units of MM intensity separating the response of the *best* site from the response of a nearby *worst* site. A difference of three to four MM units is therefore expected between the response of Zone 1 and Zone 5. The response of Zone 2 is expected to be slightly stronger than Zone 1.

In terms of MM intensity the response of Zone 1 is expected to be MM V with some VI, Zone 2 is MM VI, and Zone 5 is MM VIII-IX (Table 2).

Scenario 2: The effects of a Scenario 2 event (a large, local Wellington Fault earthquake) will be a marked increase in the shaking throughout the study area, relative to Scenario 1, a decrease in the average difference in shaking between Zone 1 and Zone 5, and an increase in the variability of shaking within each zone.

SCENARIO 1				
Zones	**MM Intensity**	**Peak ground acceleration (g)**	**Duration**	**Amplification of ground motion (FSR)**
1	V-VI	0.02-0.06	<5 sec	1-3x
2	VI	0.02-0.1	2-3x	2-5x
5	VIII-IX	<0.3 generally between 0.1-0.2	>3x	10-20x
SCENARIO 2				
Zone	**MM Intensity**	**Peak ground acceleration (g)**	**Duration**	
1	VIII	0.3-0.6	15-40 sec	
2	VIII-IX	0.3-0.6	1-2x	
5	X-XI	0.5-0.8	>2x	

Table 2: Ground motion parameters for the ground shaking hazard zones in the Porirua area.

An important factor influencing ground shaking for a Scenario 2 event is distance from the earthquake source. In general, shaking decreases with increased distance from the source. The Porirua study area is about 4 kilometres from the Wellington Fault. Therefore sites in Porirua are expected to shake less than similar sites in the Lower Hutt valley.

Epicentral intensities for the 1989 Loma Prieta earthquake were MM VIII. However, the Loma Prieta earthquake was smaller than the Scenario 2 event (M 7.1 compared to M 7.5). Epicentral intensities for similarly sized New Zealand earthquakes have been MM IX (1848 Marlborough), MM IX-X (1931 Hawkes Bay) and MM VIII-IX (1968 Inangahua).

On the basis of these relationships, MM VIII is expected in Zone 1. In Zone 2 the response is expected to be MM VIII-IX. Violent shaking, MM X-XI, is expected in Zone 5 (Table 2).

Some of the possible ground damage effects that are likely in the various hazard zones for the two earthquake scenarios are given in Table 3. These are based largely on the expected MM intensities, as well as knowledge of earlier damaging earthquakes in the Wellington Region and elsewhere.

2.5.2 **Peak horizontal ground acceleration**

Scenario 1: Peak ground acceleration for Zone 1 is expected to be in the order of 0.02 to 0.06g. This compares to the 0.06g recorded during the Loma Prieta earthquake at a hard rock site 95 kilometres from the epicentre. Accelerations of 0.02 to 0.1g are expected in Zone 2. For Zone 5, average accelerations of 0.1 to 0.2g are expected. Accelerations could be as high as 0.3g, based on the 0.29g acceleration recorded 97 kilometres from the Loma Prieta epicentre on a *soil site* (Table 2).

Scenario 2: The average peak ground accelerations expected for Scenario 2, based on a variety of attenuation relations and geological site considerations are as follows: Zone 1, 0.3 to 0.6g; Zone 2, 0.3 to 0.6g; and Zone 5, 0.5 to 0.8g (Table 2).

2.5.3 **Duration of strong shaking**

Duration provides a qualitative estimate of the effects that local geological deposits can have in increasing the length of time a site will experience strong shaking. In general, amplitudes and durations of shaking increase with decreasing firmness of the underlying sediment. This has been observed in the Wellington area for non-damaging earthquakes and elsewhere for larger damaging earthquakes. In this study *duration* refers to the time between the first and last accelerations that exceed 0.05g.

SCENARIO 1 EARTHQUAKE	
Hazard Zones	**Ground conditions and likely effects**
1	**"Greywacke"/Argillite Bedrock** : Little ground damage. Small (<100 m³) local failures on steep slopes and unsupported cut batters. Small local failures on cuts in weathered gravels.
2	**Alluvial Deposits** : Little or no significant damage likely. Small local failures on river banks possible.
5	**Soft Sediments** : Widespread minor slumping of steep banks (>2 m high). Localised lateral spreading of ground adjacent to river and stream banks with sand ejection (liquefaction effects). Differential settlement and collapse possible in some areas - especially in areas where the water table is close to the ground surface and adjacent to river banks.
SCENARIO 2 EARTHQUAKE	
Hazard Zones	**Ground conditions and likely effects**
1	**"Greywacke" Bedrock** : Small failures of bedrock and surficial deposits. Widespread on steep slopes and on steep unsupported cuts (>2 m high).
2	**Alluvial Deposits** : Only little significant ground damage expected. Small localised failures of river banks and cuts. Cracking and lateral spreading likely adjacent to river and stream channels with sand ejection due to liquefaction. Minor settlement and collapse of saturated materials in most places.
5	**Soft Sediments** : Effects as for Zones 2 and 3-4 - except that damage will be widespread, and at a greater scale. Liquefaction effects (sand ejection, cracking, lateral spreading and settlement) would be widespread, and seriously damaging in some places, especially areas adjacent to river and stream courses.

Table 3: Ground damage effects likely in each ground shaking hazard zone for the two earthquake scenarios.

Scenario 1: The expected duration of strong shaking in Zone 1 during a Scenario 1 event is less than 5 seconds (Table 2). The expected increase in duration, relative to bedrock, is 2 to 3 times in Zone 2 and more than 3 times in Zone 5.

Scenario 2: Length of fault rupture is a controlling factor regarding the duration of near-source ground shaking. The Loma Prieta earthquake produced about 10 seconds of strong shaking, resulting from a 40 kilometres bilateral rupture (rupture propagation from the centre of the fault to the ends). Had the rupture been unilateral (rupture propagation from one end of the fault) the shaking would have lasted much longer, perhaps up to 20 seconds. Rupture of the Wellington Fault in Scenario 2 is expected to be about twice as long as the rupture that produced the Loma Prieta earthquake. The duration of shaking for Zone 1 during Scenario 2 is expected to be 15 to 40 seconds, by comparison with the Loma Prieta event and depending on whether the rupture propagates bilaterally or unilaterally. The increase in duration, relative to Zone 1, is 1 to 2 times for Zone 2 and greater than 2 times for Zone 5 (Table 2).

2.5.4 **Amplification of ground motion spectrum**

Characteristic peak Fourier spectral ratios are summarised in Table 2. The results are useful for determining relative shaking and for identifying the frequencies over which this shaking will be most strongly amplified during certain earthquakes, specifically Scenario 1 type events.

Spectral ratios vary from 1 to 3 for most firm sites and up to about 20 for flexible sediment sites. Ground motion amplification at most of the sites in the Porirua study area occur over a broad frequency band from 0.5 to 5Hz. However, some sites, particularly those in Zone 5, exhibit a narrow (resonant) frequency response. Results from other studies suggest that the frequency of amplified shaking during small earthquakes remains the same for larger damaging earthquakes. Site resonance is of most concern where built structures have natural periods that coincide with the resonant period band(s) of strong ground shaking.

Even though the ground motion amplifications measured in Porirua were recorded during non-damaging earthquakes it is significant to note that intensity maps, prepared in the 1970s for the San Francisco Bay area, anticipated all of the areas that experienced high intensity shaking during the 1989 Loma Prieta earthquake. The level of amplification during even larger ground motions at near-source sites is unresolved. An amplification of FSR greater than 5 is unlikely to persist to extreme motions. This is ecause at high strain levels weak sediments begin to behave in a non-linear fashion - they begin to lose strength and increase wave attenuation or damping. Nevertheless, variations in the nature of seismic response can still be expected from one zone to another. High amplification of small bedrock ground motions, such as the Scenario 1 bedrock motions, means that significant local damage in Zone 5 could result from an earthquake that would cause little or no damage in Zone 1. Amplification of small bedrock ground motions are best characterised by measured spectral ratios and are therefore given only for Scenario 1.

3. ASSUMPTIONS AND LIMITATIONS

Important assumptions that limit the certainty with which the ground shaking hazard zones can either be mapped or quantified are discussed below.

(1) Within each hazard zone there are isolated occurrences of materials that may cause ground motions that are not typical of the zone as a whole. The mapped fills in Porirua East are on bedrock and are included with Zone 1. However, these fills are over 20 metres thick in places and may respond more like Zone 2. Conversely, some areas mapped in Porirua as Zone 5 may not be underlain by enough sediment to cause high amplifications of ground motion. At these sites a more favourable response may result.

Significant variations in amplified resonant response over relatively short distances in some areas, emphasise the importance of site specific studies to determine the nature and response of the materials at a site.

(2) High amplifications were recorded at Titahi Bay but the distribution of the materials causing these amplifications is not well defined. The poorly resolved boundary around the Zone 5 area is denoted as a *dashed* line on the ground shaking hazard map.

(3) Amplification of ground motion due to topographic effects has not been addressed for this study. Though probably localised, these effects can be pronounced.

(4) There is a marked directionality in the response at some strong motion sites at select frequencies. It is unclear whether this directionality is consistent in different earthquakes.

(5) The ground damage effects given in Table 3 are estimated from a general knowledge of past earthquakes in the Wellington Region and elsewhere, and have not been the subject of detailed study.

(6) Scenario 2 ground motion parameters are defined with less certainty. There is a worldwide lack of near-source ground motion data recorded during large earthquakes. During a large local earthquake near-source seismic wave propagation will be complex and non-uniform, and ground strains will be large enough to cause some sediments to exhibit non-linear response. These effects will tend to increase the variability of shaking within a zone, decrease the average difference in shaking between zones and decrease the certainty with which expected ground motions can be characterised. Also, near-source ground motions for an earthquake associated with a long fault rupture, such as Scenario 2, may be correlated with proximity to local asperities along the fault rupture, rather than proximity to the fault itself.

(7) The information given in this booklet and on the accompanying map is the result of a regional scale multi-disciplinary study of ground shaking hazard. The booklet and map provide useful information for the mitigation of ground shaking hazard in the Porirua study area but should not be used to replace site specific studies.

Detailed geological mapping, additional penetrometer probing, seismograph instrumentation, and topographic and mathematical modelling would resolve some of these issues.

4. SUMMARY

The geographic variation in ground shaking was defined using information from drillhole logs, microearthquake records, penetrometer logs and from numerical modelling. Three ground shaking hazard zone were established. These are Zone 1, Zone 2 and Zone 5. The geographic distribution of the zones is shown on the accompanying map.

Zone 1 areas are the least hazardous and are underlain by bedrock. Zone 2 areas show low to moderate amplification of earthquake shaking and are underlain by firm material. Zone 5 areas show high to very high amplification of earthquake motion and are underlain by more than 10 metres of soft and/or loose material.

The expected response of each ground shaking hazard zone to two earthquake scenarios is given by Modified Mercalli intensity, peak ground acceleration, duration and amplification of ground motion parameters. The two parameters most easily understood are MM intensity and duration. For a large distant earthquake (Scenario 1) MM values range from V-VI in Zone 1 to VIII-IX in Zone 5. The response will range from *some alarm and damage* in Zone 1 areas to *general panic and substantial damage* in Zone 5 areas. Strong shaking will last for less than 5 seconds in Zone 1 areas but continue for more than 15 seconds in Zone 5 areas. For a large earthquake centred on the Wellington Fault (Scenario 2), there is less difference between the zones, with strong shaking experienced everywhere. However, Zone 5 areas are expected to shake strongly for twice the duration of Zone 1 sites and to experience MM intensity 1 to 2 units higher on the scale.

Important assumptions that limit the certainty with which the ground shaking hazard zones can either be mapped or quantified must be considered when interpreting the hazard information.

APPENDICES

APPENDIX 1: CONTRIBUTING REPORTS AND REFERENCES

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APPENDIX 2: GLOSSARY OF TECHNICAL TERMS

Active fault A fault with evidence of surface movement in the last 50000 years or repeated surface movement in the last 500000 years.

Hazard A potentially damaging physical event.

Liquefaction Process by which water-saturated sediment temporarily loses strength, usually because of strong shaking and behaves as a fluid.

Risk The combination of a natural hazard event and our vulnerability to it. Risk can be specified in terms of expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular natural hazard.

Seiche Oscillation of the surface of an enclosed body of water owing to earthquake shaking.

Seismic To do with earthquake or earthquake-like motions in the earth.

Tsunami An impulsively generated sea wave of local or distant origin that results from seafloor fault movement, large scale seafloor slides or volcanic eruption on the seafloor.

APPENDIX 3: MODIFIED MERCALLI INTENSITY SCALE

MM 1 Not felt by humans, except in especially favourable circumstances but birds and animals may be disturbed. Reported mainly from the upper floor of buildings more than 10 storeys high. Dizziness or nausea may be experienced. Branches of trees, chandeliers, doors and other suspended systems of long natural period may be seen to move slowly. Water in ponds, lakes and reservoirs may be set into seiche oscillation.

MM II Felt by a few persons at rest indoors, especially by those on upper floors or otherwise favourably placed. The long period effects listed under MM I may be more noticeable.

MM III Felt indoors but not identified as an earthquake by everyone. Vibration may be likened to the passing of light traffic. It may be possible to estimate the duration but not the direction. Hanging objects may swing slightly. Standing motorcars may rock slightly.

MM IV Generally noticed indoors but not outside. Very light sleepers may be wakened. Vibration may be likened to the passing of heavy traffic, or to the jolt of a heavy object falling or striking the building. Walls and frames of buildings are heard to creak. Doors and windows rattle. Glassware and crockery rattle. Liquids in open vessels may be slightly disturbed. Standing motorcars may rock and the shock can be felt by their occupants.

MM VI Felt by all. People and animals alarmed. Many run outside. Difficulty experienced in walking steadily. Slight damage to Masonry D. Some plaster cracks or falls. Isolated cases of chimney damage. Windows, glassware and crockery broken. Objects fall from shelves and pictures from walls. Heavy furniture overturned. Small church and school bells ring. Trees and bushes shake or are heard to rustle. Loose material may be dislodged from existing slips, talus slopes, or shingle slides.

MM VII General alarm. Difficulty experienced in standing. Noticed by drivers of motorcars. Trees and bushes strongly shaken. Large bells ring. Masonry D cracked and damaged. A few instances of damage to Masonry C. Loose brickwork and tiles dislodged. Unbraced parapets and architectural ornaments may fall. Stone walls cracked. Weak chimneys broken, usually at the roofline. Domestic water tanks burst. Concrete irrigation ditches damaged. Waves seen on ponds and lakes. Water made turbid by stirred-up mud. Small slips and caving in of sand and gravel banks.

MM VIII Alarm may approach panic. Steering of motorcars affected. Masonry C damaged, with partial collapse. Masonry B damaged in some cases. Masonry A undamaged. Chimneys, factory stacks, monuments, towers and elevated tanks twisted or brought down. Panel walls thrown out of frame structures. Some brick veneers damaged. Decayed wooden piles broken. Frame houses not secured to the foundations may move. Cracks appear on steep slopes and in wet ground. Landslips in roadside cuttings and unsupported excavations. Some tree branches may be broken off. Changes in the flow or temperature of springs and wells may occur. Small earthquake fountains may form.

MM IX General panic. Masonry D destroyed. Masonry C heavily damaged, sometimes collapsing completely. Masonry B seriously damaged. Frame structures racked and distorted. Damage to foundations general. Frame houses not secured to the foundations shifted off. Brick veneers fall and expose frames. Cracking of the ground conspicuous. Minor damage to paths and roadways. Sand and mud ejected in alleviated areas, with the formation of earthquake fountains and sand craters. Underground pipes broken. Serious damage to reservoirs.

MM X Most masonry structures destroyed, together with their foundations. Some well built wooden buildings and bridges seriously damaged. Dams, dykes and embankments seriously damaged. Railway lines slightly bent. Cement and asphalt roads and pavements badly cracked or thrown into waves. Large landslides on river banks and steep coasts. Sand and mud on beaches and flat land moved horizontally. Large and spectacular sand and mud fountains. Water from rivers, lakes and canals thrown up on banks.

MM XI Wooden frame structures destroyed. Great damage to railway lines and underground pipes.

MM XII Damage virtually total. Practically all works of construction destroyed or greatly damaged. Large rock masses displaced. Lines of sight and level distorted. Visible wave-motion of the ground surface reported. Objects thrown upwards into the air.

APPENDIX 4: GEOLOGICAL DESCRIPTIONS OF HAZARD ZONES

Zone 1: Greywacke bedrock, including areas overlain by less than 10 metres of deeply weathered gravel and loess, or well engineered fill.

Zone 2: Alluvial gravel and fan alluvium; fine to coarse gravel, up to 200 metres thick, with some beds and lenses of finer grained sediment (sand, silt, clay, and peat) usually less than 5 metres thick. The coarse sediments typically have moderate to high SPT values (20 to 60). At Titahi Bay, 10 to 20 metre thickness of extremely weak silty sandstone with lenses of gravel or about a 5 to 10 metre thickness of windblown sand.

Zone 5: Soft sediment (fine sand, silt, clay and peat) up to 10 to 30 metres thick, at or very near the surface, underlain by bedrock or a variable thickness of gravel and other finer grained sediment. Shear wave velocities for these *flexible* sediments at Porirua are in the order of 110 metres/second.

GROUND SHAKING HAZARD
LOWER HUTT

NOTES TO ACCOMPANY

SEISMIC HAZARD MAP SERIES: GROUND SHAKING HAZARD MAP SHEET 3 LOWER HUTT (FIRST EDITION) 1:25000

OCTOBER 1992

2

Publication WRC/PP-T-92/47

Compiled by

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POLICY AND PLANNING DEPARTMENT

WELLINGTON REGIONAL COUNCIL

1. INTRODUCTION

1.1 BACKGROUND

The occurrence of earthquakes in the Wellington Region is inevitable due to its location at the boundary of two crustal plates. Earthquakes have the potential to cause significant adverse effects within the Region, including loss of life, injury, and social and economic disruption. In recognition of these potential effects, the Wellington Regional Council initiated a project in 1988 to:

* Assess the risks posed by earthquakes.
* Identify mitigation options.
* Implement measures to ensure that the level of risk is acceptable.

The first step in the project is to define the characteristics of the hazard. Information on the type and magnitude of possible effects, the probability of these occurring and the location of the effects within the Region is required. For the purposes of the project, *earthquake hazard* has been divided into a number of separate but interrelated components, including:

* Ground shaking.
* Surface fault rupture.
* Liquefaction and ground damage.
* Landsliding.
* Tsunami.

Although not all the effects will occur during every earthquake, and many will be localised all components must be considered to obtain a complete picture of earthquake hazard.

1.2 PURPOSE OF MAP AND BOOKLET

A series of six map sheets, with accompanying booklets, have been compiled to describe the *ground shaking hazard* for the main metropolitan areas in the Region (refer to Index Map on accompanying map sheet):

* Sheet 1 - Wellington.
* Sheet 2 - Porirua and Tawa.
* Sheet 3 - Lower Hutt.
* Sheet 4 - Upper Hutt.
* Sheet 5 - Paekakariki, Paraparaumu, Waikanae and Otaki.
* Sheet 6 - Featherston, Greytown, Carterton and Masterton.

The purpose of the maps is to show the geographic variation in ground shaking hazard that could be expected during certain earthquake events. **The map sheets and booklets have been compiled from Wellington Regional Council reports and detailed reports prepared for the Wellington Regional Council by DSIR Geology and Geophysics, Land Resources and Physical Sciences, and Victoria University of Wellington.** A list of the reports is given in Appendix 1.

The intention of the map and booklet series is to raise public awareness of ground shaking hazard in the Wellington Region. The information will be useful to a range of potential users, including land use planners, civil defence organisations, land developers, engineers, utility operators, scientists and the general public.

Information on active faults in the western part of the Region has been published in a map series by the Wellington Regional Council - *Major Active Faults of the Wellington Region* (Map sheets 1, 2 and 3: 1991). Tsunami hazard information for Wellington Harbour is also available.

1.3 BOOKLET STRUCTURE

This booklet is divided into four main parts. Part 1 provides background information on the study. Part 2 outlines the hazard assessment approach and details the mapping methodology. Parameters used to quantify the hazard zones are also discussed. Part 3 states the assumptions and limitations that determine the certainty with which the hazard zones can either be mapped or quantified. A brief summary is given in Part 4.

Technical terms are defined in Appendix 2.

2. HAZARD ASSESSMENT

2.1 DATA SOURCES

The geographic variation in earthquake ground shaking was defined using geological and geotechnical information from drillhole logs, microearthquake records, strong motion earthquake records, penetrometer logs and gravity surveys. Numerical techniques to model the seismic response of sediments were also used.

The distribution of geological materials in the Lower Hutt area (Wainuiomata, Eastbourne and Lower Hutt valley) was mapped primarily on an assessment of 850 drillhole logs, of which 370 are deeper than 5 metres, and 20 deeper than 50 metres. The properties of the materials in Wainuiomata and Eastbourne were further quantified using 14 cone- and two seismic-cone penetrometer probings. The seismic response of the flexible sediments at

Wainuiomata was modelled. The ground response of the geological materials was assessed at 23 sites in the Lower Hutt area using records from 33 microearthquakes and at 7 sites in the Lower Hutt valley using strong motion earthquake records from up to 14 events.

2.2 EARTHQUAKE SCENARIOS

The Wellington Region is located across the boundary of the Pacific and Australian plates (Figure 1). As a consequence, the Region is cut by four major active faults, and is frequently shaken by moderate to large earthquakes (Figures 2 and 3).

Because no single earthquake event adequately describes the potential ground shaking hazard in the Region, two earthquake scenarios were used to define the hazard.

Scenario 1 is for a large, distant, shallow earthquake that produces Modified Mercalli intensity (MM) V-VI on bedrock (Appendix 3). It is expected that this type of earthquake will produce the largest variation in ground response. Scenario 1 implies minor damage to structures founded on the *best* sites and significant damage to certain structures on the *worst* sites. An example of such an event would be a Magnitude (M) 7 earthquake centred about 100 kilometres from the study area at a depth of less than 30 kilometres. Twenty years is a minimum estimate for the return time of a Scenario 1 event. This return time is derived from the historical occurrence of both large earthquakes and moderate sized local events. A maximum estimate is 80 years, which is the return time of MM VII or greater shaking at bedrock sites in the Wellington Region.

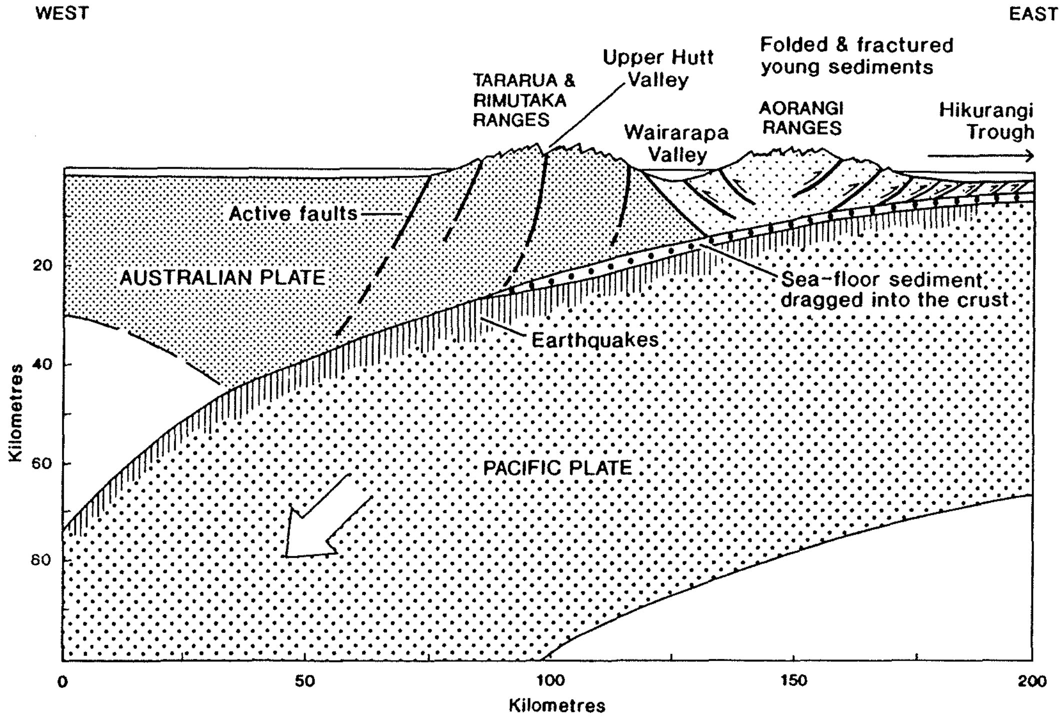

Figure 1: Source of earthquakes at plate boundary and along active faults. (After Stevens, 1991).

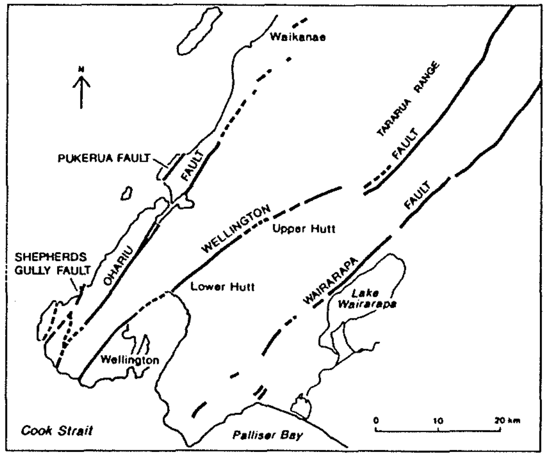

Figure 2: Active faults in the western part of the Wellington Region. (After Van Dissen, 1991).

Scenario 2 is for a large earthquake centred on the Wellington-Hutt Valley segment of the Wellington Fault. Rupture of this segment is expected to be associated with a Magnitude 7.5 earthquake at a depth less than 30 kilometres, and up to 5 metres of horizontal and 1 metre vertical displacement at the ground surface. The return time for such an event is about 600 years and the probability of this event occurring in the next 30 years is estimated to be 10 percent. The values for near-source shaking resulting from a Scenario 2 earthquake are given with less certainty (refer to Section 2.5). This is because there are so few near-source ground motion data from large earthquakes, and factors such as

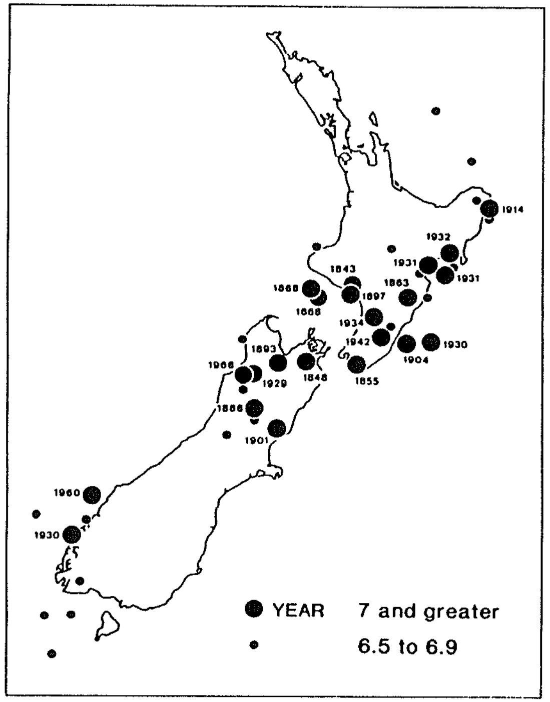

Figure 3: Epicentres of shallow earthquakes of magnitude 6.5 and greater since 1840. (After Van Dissen, 1991).

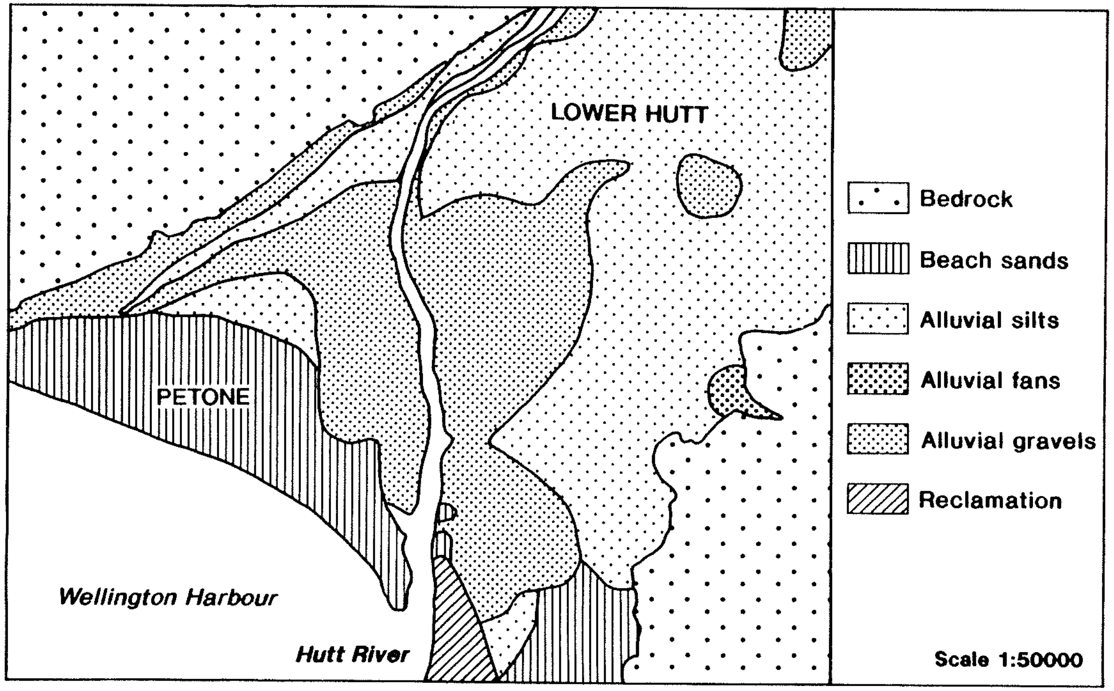

Figure 4: Surface geology deposits in the Petone-Lower Hutt area. (After Read *et al*, 1991).

proximity to local asperities along the rupture plane and random cancellation and reinforcement of seismic waves can locally suppress the effects caused by near-surface geological deposits. Furthermore, amplification of some local geological deposits will not occur at particular ground shaking frequencies and strengths.

2.3 MAPPING METHODOLOGY

2.3.1 **Surface geology**

The surface geology of the Lower Hutt area was mapped using six units:

* Reclamation.
* Alluvial gravels.
* Alluvial fans.
* Alluvial silts.
* Beach sands.
* Bedrock (Torlesse Supergroup Greywacke).

The distribution of surface geology deposits in the Lower Hutt to Petone area is shown in Figure 4. Subsurface geology was defined using information from drilling, supplemented in the Lower Hutt valley where the depth to bedrock is greater, by gravity measurements. In the Wainuiomata and Eastbourne areas, little subsurface information was available, apart from cone penetration test results. Geological cross-sections through the Wainuiomata and Lower Hutt valley areas are given in Figures 5 and 6 respectively.

The geology information provided the base for the ground shaking hazard zones.

2.3.2 **Weak ground motions**

variety of geological ground conditions, ranging from bedrock to significantly thick soft *flexible* sediments. The relative shaking response of each site was expressed as an averaged ratio of the Fourier spectra of the seismograms compared to a reference bedrock site.

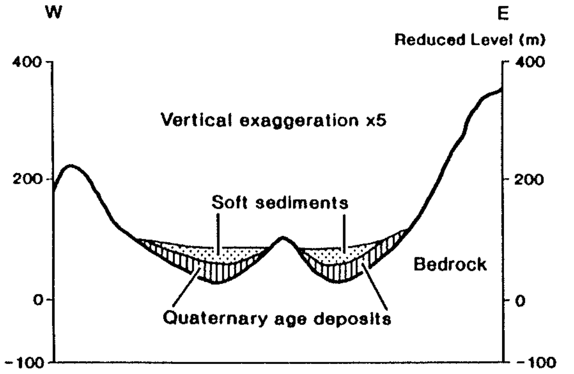

Figure 5: Geological cross section through the Wainuiomata area. (After Read *et al*, 1991).

The highest spectral amplifications recorded in the Lower Hutt area were from two sites in Wainuiomata. Both sites have spectral ratios of 16 to 18 relative to a hard rock reference site and were underlain by up to 35 metres of soft *flexible* sediment with shear wave velocities in the order of 90 to 150 metres/ second.

Five stations in the Lower Hutt valley were sited on bedrock or deeply weathered gravel and loess underlain by bedrock. These stations showed little if any amplification of microearthquake ground motions relative to a hard rock reference site. The spectral ratios were all less than 4. Three strong motion instruments were sited on bedrock or deeply weathered rock. Compared to the response spectra of the reference site, one site showed slightly amplified ground motion, the other slightly attenuated motion.

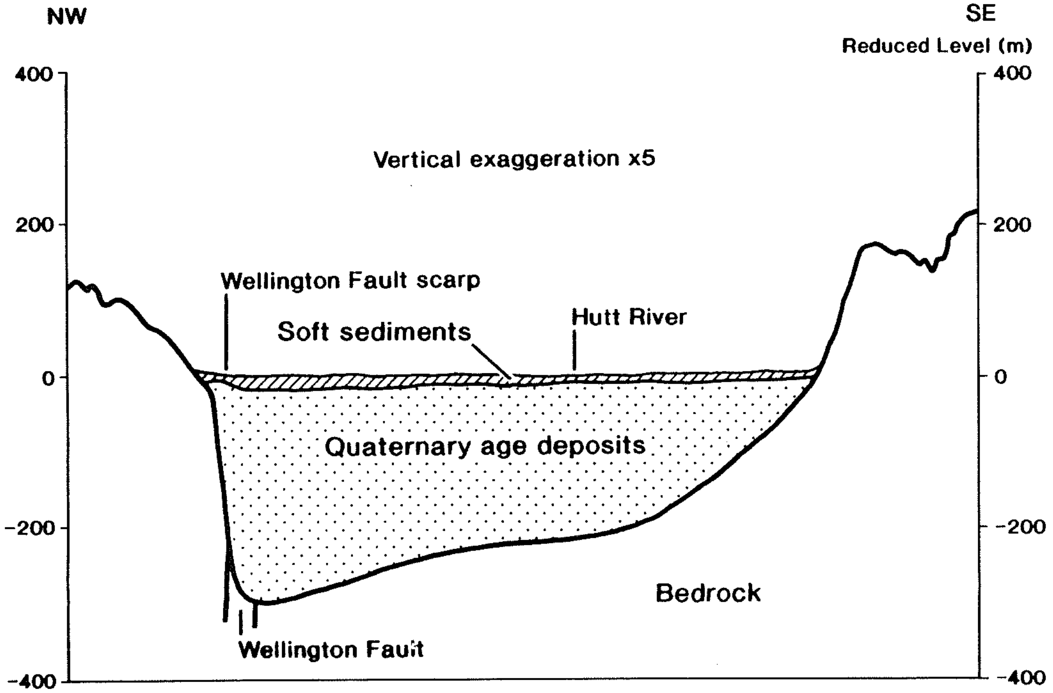

Figure 6: Geological cross section through the Lower Hutt Valley area. (After Read *et al*, 1991).

Of the 16 seismographs sited on the unconsolidated sediments in the Lower Hutt valley six had spectral ratios of less than 5. These sites are all underlain by less than 200 metres of gravel, and some sites are underlain by as little as 10 metres of gravel. Also, none of these sites are underlain by more than about 5 metres of near-surface *flexible* sediment.

The highest amplifications recorded in the Lower Hutt valley were at Petone where total sediment thickness and thickness of soft near-surface sediment are at a maximum. Here, two sites had averaged spectral ratios of 12 to 15 relative to a hard rock reference site. For sites near the Hutt River, and further northeast and east from Petone, averaged spectral ratios were less than 8.

2.3.3 Penetrometer probings

The nature of the near-surface material at various sites was further defined using cone penetrometer and seismic-cone penetrometer probing. In order to locate possible deposits of soft *flexible* sediment in the Eastbourne area five cone penetrometer tests were carried out at likely locations. No significant soft or weak layers were identified below about three metres depth. All probes reached refusal in dense sand or gravel, except at Bishop Park where probing was stopped by very stiff clayey silty sand. The results of the CPT investigations at Bishop Park (Eastbourne) are shown in Figure 7.

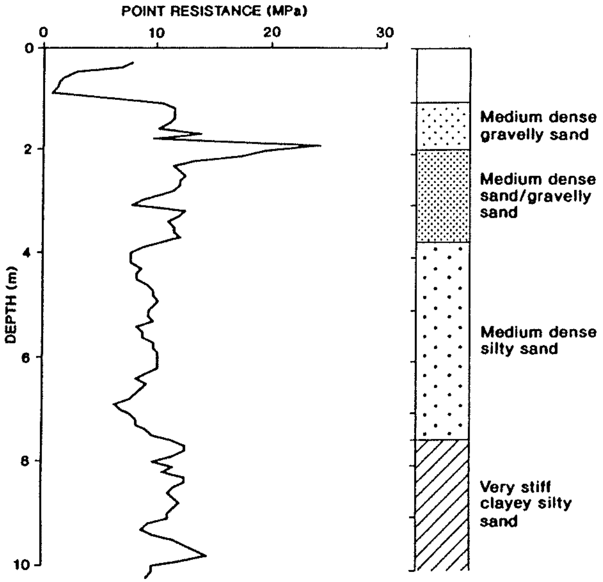

Figure 7: Cone penetrometer test results at Bishop Park, Eastbourne. (After Stephenson and Barker, 1991).

2.3.4 Ground shaking hazard zones

Based on the distribution of geological materials and the measured response of these materials to seismic waves the Lower Hutt study area was mapped into four ground shaking hazard zones; Zone 1, Zone 2, Zone 3-4, and Zone 5 (refer to accompanying map sheet).

Zone 1, the least hazardous zone, is characteristically underlain by bedrock, and typically shows very low to low amplification of seismic waves.

Zone 2 areas are underlain by firm material, including compact gravel and stiff to hard clay or less than 5 metres of soft and/or loose material, and show low to moderate amplification of earthquake shaking relative to bedrock.

MATERIAL DESCRIPTION	ENGINEERING PROPERTIES			
	DRILLING/PROBING		LABORATORY TESTING	
	SPT (Blows/300 mm)	CPT (Cone Res. MPa)	Water Content (%)	Void Ratio
LOWER HUTT VALLEY				
Soft sediments (to 27 m depth in lower valley)				
Soft to firm silts, sometimes organic	1 - 10	1 - 2	50 - 100	0.80 - 1.50
Loose sands or gravelly sands	5 - 20	5 - 10	40 - 60	0.60 - 1.10
Firm silty clay	10 - 15	1 - 3	30 - 60	0.70 - 1.00
Loose sandy gravel	10 - 40	>20	Not tested	Not tested
Coarse-grained alluvial sediments				
Compact sandy gravels (alluvial)	30 - >60		Not tested	Not tested
Silty gravelly sands (fan alluvium)	15 - 30	>20	Not tested	Not tested
WAINUIOMATA				
Soft sediments				
Soft to firm silts	3 - 10	1 - 2	Not tested	Not tested
Silty sandy gravels (fan alluvium)	10 - 30	10 - 15	Not tested	Not tested
Coarse ground alluvial sediments				
Compact sandy gravels	30 - >60			
EASTBOURNE				
Loose sands or gravelly sands		5 - 20	Not tested	Not tested

Table 1: Summary of typical geotechnical properties for Quaternary age materials in the Lower Hutt valley and Wainuiomata

Zone 3-4 represents a transition zone between the low to moderate amplification of ground shaking anticipated in Zone 2, and the high to very high amplification anticipated in Zone 5. Zone 3-4 areas are typically underlain by 5 to 10 metres of near surface soft and/or loose material and are characterised by moderate to high amplification of earthquake ground motion relative to bedrock.

Zone 5 areas are underlain by more than 10 metres of soft and/or loose material. These materials generally have shear wave velocities in the order of 200 metres/second or less. Zone 5 areas are characterised by high to very high amplification of earthquake ground motion, relative to bedrock and are therefore subject to the greatest ground shaking hazard.

2.4 GEOLOGICAL DESCRIPTION OF HAZARD ZONES

Descriptions of the geological materials that typify each hazard zone are given in Appendix 4. A summary of some of the engineering properties of the geological materials in the Lower Hutt valley, Wainuiomata and Eastbourne areas is given in Table 1.

2.5 QUANTIFICATION OF HAZARD ZONES

The shaking response of the ground shaking hazard zones was assessed for the two earthquake scenarios (as described in Part 2.2). The response of each zone was expressed as a set of ground motion parameters, comprising:

- Expected Modified Mercalli intensity.
- Peak horizontal ground acceleration.
- Duration of strong shaking.
- Amplification of ground motion with respect to bedrock - expressed as a Fourier spectral ratio.

Some of these parameters were measured directly, others were estimated using comparisons found in the published scientific and engineering literature.

The Loma Prieta earthquake (1989, San Francisco) is significant to this study because of the recorded variations in ground motion related to local geological conditions, and because the magnitude is similar to that expected for the Scenario 1 earthquake. Therefore, the values calculated for the ground motion parameters used in this study were compared with those measured for the Loma Prieta event.

SCENARIO 1

Zones		MM Intensity	Peak ground acceleration (g)	Duration	Amplification of ground motion (FSR)
1		V-VI	0.02-0.06	<5 sec	1-3x
2		VI	0.02-0.1	2-3x	2-5x
3-4		VI-VII	0.02-0.1	2-3x	5-10x
5	Naenae	VIII-IX	<0.3 generally between 0.1-0.2	>3x	10-20x
	Wainuiomata (shallow)				
	Wainuiomata (deep)				
	Lower Hutt		<0.2 generally around 0.05-0.1		

SCENARIO 2

Zone		MM Intensity	Peak ground acceleration (g)	Duration
1	near fault	IX	0.5-0.8	15-40 sec
	Wainuiomata	VIII	0.3-0.6	
2	near fault	IX-X	0.5-0.8	1-2x
	Wainuiomata	VIII-IX	0.3-0.6	
3-4		IX-X	0.5-0.8	1-2x
5	near fault	X-XI	0.6-0.8	>2x
	Wainuiomata		0.5-0.8	

Table 2: Ground motion parameters for the ground shaking hazard zones in the Lower Hutt valley and Wainuiomata areas.

2.5.1 **Modified Mercalli intensity**

Scenario 1: The Scenario 1 earthquake (a large, distant, shallow earthquake, resulting in MM V-VI shaking on bedrock) will be of sufficient duration and contain sufficient long period energy to allow strong long-period response to develop at deeper sediment sites. The shallow focal depth will allow strong surface wave effects. The result will be a marked difference between the shaking of the *worst* sediment site and the *best* firm site. It is not uncommon during an earthquake to have a spread of three to four units of MM intensity separating the response of the *best* site from the response of a nearby *worst* site. A difference of three to four MM units is therefore expected between the response of Zone 1 and Zone 5. The response of Zones 2 and 3-4 is expected to be slightly stronger than Zone 1.

In terms of MM intensity the response of Zone 1 is expected to be MM V with some VI, Zone 2 is MM VI, Zone 3-4 is MM VI-VII, and Zone 5 is MM VIII-IX (Table 2).

Scenario 2: The effects of a Scenario 2 event (a large, local Wellington Fault earthquake) will be a marked increase in the shaking throughout the study area, relative to Scenario 1, a decrease in the average difference in shaking between Zone 1 and Zone 5, and an increase in the variability of shaking within each zone.

An important factor influencing ground shaking for a Scenario 2 event is distance from the earthquake source. In general, shaking decreases with increased distance from the source. The Hutt valley area is within 4 kilometres of the Wellington Fault. Wainuiomata is about 6 to 11 kilometres from the Fault. Therefore, sites in Wainuiomata are expected to shake less than similar sites in the Lower Hutt valley.

Epicentral intensities for the 1989 Loma Prieta earthquake were MM VIII. However, the Loma Prieta earthquake was smaller than the Scenario 2 event (M 7.1 compared to M 7.5). Epicentral intensities for similarly sized New Zealand earthquakes have been MM IX (1848 Marlborough), MM IX-X (1931 Hawkes Bay) and MM VIII-IX (1968 Inangahua).

SCENARIO 1 EARTHQUAKE	
Hazard Zones	**Ground conditions and likely effects**
1	**"Greywacke"/Argillite Bedrock** : Little ground damage. Small (<100 m³) local failures on steep slopes and unsupported cut batters. Small local failures on cuts in weathered gravels.
2	**Alluvial Deposits** : Little or no significant damage likely. Small local failures on river banks possible.
3-4	**Thicker Alluvial Deposits** : Little widespread damage expected. Small localised failures of banks adjacent to rivers, streams, or cuts. Some local cracking and sand ejection possible at MM VII.
5	**Soft Sediments** : Widespread minor slumping of steep banks (>2 m high). Localised lateral spreading of ground adjacent to river and stream banks with sand ejection (liquefaction effects). Differential settlement and collapse possible in some areas - especially in areas where the water table is close to the ground surface and adjacent to river banks.
SCENARIO 2 EARTHQUAKE	
Hazard Zones	**Ground conditions and likely effects**
1	**"Greywacke" Bedrock** : Small failures of bedrock and surficial deposits. Widespread on steep slopes and on steep unsupported cuts (>2 m high).
2	**Alluvial Deposits** : Only little significant ground damage expected. Small localised failures of river banks and cuts. Cracking and lateral spreading likely adjacent to river and stream channels with sand ejection due to liquefaction. Minor settlement and collapse of saturated materials in most places.
3-4	
5	**Soft Sediments** : Effects as for Zones 2 and 3-4 - except that damage will be widespread, and at a greater scale. Liquefaction effects (sand ejection, cracking, lateral spreading and settlement) would be widespread, and seriously damaging in some places, especially areas adjacent to river and stream courses.

Table 3: Ground damage effects likely in each ground shaking hazard zone for the two earthquake scenarios.

On the basis of these relationships, MM IX is expected near the Wellington Fault in Zone 1. Further from the Fault, MM VIII is anticipated in Wainuiomata for Zone 1. MM IX-X is expected near the Fault for Zone 2, with MM VIII-IX further away in Wainuiomata. The expected Zone 3-4 response, found only near the Fault, is MM IX-X. Violent shaking, MM X-XI, is expected in Zone 5 both near the Fault and in Wainuiomata (Table 2).

Some of the possible ground damage effects that are likely in the various hazard zones for the two earthquake scenarios are given in Table 3. These are based largely on the expected MM intensities, as well as knowledge of earlier damaging earthquakes in the Wellington Region and elsewhere.

2.5.2 **Peak horizontal ground acceleration**

Scenario 1: Peak ground acceleration for Zone 1 is expected to be in the order of 0.02 to 0.06g. This compares to the 0.06g recorded during the Loma Prieta earthquake at a hard rock site 95 kilometres from the epicentre. Accelerations of 0.02 to 0.1g are expected in Zones 2 and 3-4. For Zone 5, in Wainuiomata and Naenae, average accelerations of 0.1 to 0.2g are expected. Accelerations could be as high as 0.3g, based on the 0.29g acceleration recorded 97 kilometres from the Loma Prieta epicentre on a *soil site*. Strong long period response is also anticipated for the deepest sediment sites in the Lower Hutt valley, Zone 5. However, strong long period response is not well characterised by ground acceleration. Therefore the Lower Hutt valley Zone 5 accelerations are lower than the accelerations expected for the *thinner* sediment Zone 5 areas in Wainuiomata. Accelerations of less than 0.2g, probably in the order of about 0.05g, are expected for Zone 5 in the southern Lower Hutt valley (Table 2).

Scenario 2: The average peak ground accelerations expected for Scenario 2, based on a variety of attenuation relations and geological site considerations are as follows: Zone 1, 0.5 to 0.8g in Lower Hutt valley (near the Fault), 0.3 to 0.6g in Wainuiomata; Zone 2, 0.5 to 0.8g in Lower Hutt valley, 0.3 to 0.6g in Wainuiomata; Zone 3-4, 0.5 to 0.8g and Zone 5, 0.6 to 0.8g in Lower Hutt valley, 0.5 to 0.8g in Wainuiomata (Table 2).

2.5.3 **Duration of strong shaking**

Duration provides a qualitative estimate of the effects that local geological deposits can have in increasing the length of time a site will experience strong shaking. In general, amplitudes and durations of shaking increase with decreasing firmness of the underlying sediment. This has been observed in the Wellington area for non-damaging earthquakes and elsewhere for larger damaging earthquakes. In this study, *duration* refers to the time between the first and last accelerations that exceed 0.05g.

Scenario 1: The expected duration of strong shaking in Zone 1 during a Scenario 1 event is less than 5 seconds (Table 2). The expected increase in duration, relative to bedrock, is 2 to 3 times in Zone 2 and Zone 3-4, and more than 3 times in Zone 5.

Scenario 2: Length of fault rupture is a controlling factor regarding the duration of near-source ground shaking. The Loma Prieta earthquake produced about 10 seconds of strong shaking, resulting from a 40 kilometres bilateral rupture (rupture propagation from the centre of the fault to the ends). Had the rupture been unilateral (rupture propagation from one end of the fault), the shaking would have lasted much longer, perhaps up to 20 seconds. Rupture of the Wellington Fault in Scenario 2 is expected to be about twice as long as the rupture that produced the Loma Prieta earthquake. The duration of shaking for Zone 1 during Scenario 2 is expected to be 15 to 40 seconds, by comparison with the Loma Prieta event and depending on whether the rupture propagates bilaterally or unilaterally. The increase in duration, relative to Zone 1, is 1 to 2 times for Zone 2 and Zone 3-4, and greater than 2 times for Zone 5 (Table 2).

2.5.4 **Amplification of ground motion spectrum**

Characteristic peak Fourier spectral ratios are summarised in Table 2. The results are useful for determining relative shaking and for identifying the frequencies over which this shaking will be most strongly amplified during certain earthquakes, specifically Scenario 1 type events.

Spectral ratios vary from 1 to 3 for firm sites up to about 20 for *flexible* sediment sites. Ground motion amplification at most of the sites in the Lower Hutt area occur over a broad frequency band from 0.5 to 5Hz. However, some sites, particularly those in Zone 5, exhibit a narrow (resonant) frequency response. Results from other studies suggest that the frequency of amplified shaking during small earthquakes remains the same for larger damaging earthquakes. Site resonance is of most concern where built structures have natural periods that coincide with the resonant period band(s) of strong ground shaking.

Even though the ground motion amplifications measured in the Lower Hutt area were recorded during non-damaging earthquakes it is significant to note that intensity maps, prepared in the 1970's for the San Francisco Bay area, anticipated all of the areas that experienced high intensity shaking during the 1989 Loma Prieta earthquake. The level of amplification during even larger ground motions at near-source sites is unresolved. An amplification of FSR greater than 5 is unlikely to persist to extreme motions. This is because at high strain levels weak sediments begin to behave in a nonlinear fashion - they begin to lose strength and increase wave attenuation or damping. Nevertheless, variations in the nature of seismic response can still be expected from one zone to another. High amplification of small bedrock ground motions, such as the Scenario 1 bedrock motions, means that significant local damage in Zone 5 could result from an earthquake that would cause little or no damage in Zone 1. Amplification of small bedrock ground motions are best characterised by measured spectral ratios and are therefore given only for Scenario 1.

3. ASSUMPTIONS AND LIMITATIONS

Important assumptions that limit the certainty with which the ground shaking hazard zones can either be mapped or quantified are discussed below.

(1) Within each hazard zone there are isolated occurrences of materials that may cause ground motions that are not typical of the zone as a whole. In the western Hutt hills there are small terrace remnants and local areas of deeply weathered bedrock. These have been included in Zone 1 but it is possible their response could be closer to that of Zone 2.

Much of what is mapped as Zone 2 in the Lower Hutt Valley is underlain by a thin near-surface layer of alluvial silt. Usually these fine grained sediments are less than 5 metres thick and are underlain by coarser alluvial gravels. However, locally they can be more than 10 metres thick. An extreme example is at Naenae. At these *thicker* localities a less favourable response is expected.

In Eastbourne, the spacing of penetrometer probings does not preclude the existence of isolated pockets of *flexible* sediment. If thick enough these sediments would respond less favourably than the general Zone 2 response expected for most of Eastbourne.

Significant variations in amplified resonant response over relatively short distances emphasise the importance of site specific studies to determine the nature and response of the materials at a site.

(2) High amplifications were recorded at Naenae but the distribution of the materials causing these amplifications is not well defined. The poorly resolved boundary around the Zone 5 area is denoted as a *dashed* line on the ground shaking hazard map.

(3) The Zone 5 and Zone 3-4 boundaries in the southern Lower Hutt valley are gradational, reflecting the gradual down-valley increase in both total sediment thickness and thickness of soft near-surface *flexible* sediment. These boundaries are marked on the ground shaking hazard map as a *dot-dash* line. The change in response from one zone to the other is expected to occur over distances of about 300 metres perpendicular to the boundary. The boundary as shown on the map is accurate to within about 200-800 metres, depending on the spacing and quality of the constraining data.

(4) The weak motion data suggested that the Zone 5 boundary in the Lower Hutt valley should be located southwest of the Hutt River, the *dotted* line on the accompanying ground shaking hazard map. The strong motion data, however, suggested that the maximum amplification measured at a site in Petone is similar to that at a site in Lower Hutt, though the two sites have a different frequency response. This suggests that the northeastern extent of Zone 5 should include central Lower Hutt. Because of this difference it was considered more appropriate to adopt a conservative interpretation. Therefore, Lower Hutt is included in Zone 5. In doing so, the uncertainty regarding the northeastern extent on the Zone 5 boundary is acknowledged.

(5) Amplification of ground motion due to topographic effects has not been addressed for this study. Though probably localised, these effects can be pronounced.

(6) There is a marked directionality in the response at some strong motion sites at select frequencies. It is unclear whether this directionality is consistent in different earthquakes.

(7) The ground damage effects given in Table 3 are estimated from a general knowledge of past earthquakes in the Wellington Region and elsewhere, and have not been the subject of detailed study.

(8) Scenario 2 ground motion parameters are defined with less certainty. There is a worldwide lack of near-source ground motion data recorded during large earthquakes. During a large local earthquake, near-source seismic

wave propagation will be complex and non-uniform, and ground strains will be large enough to cause some sediments to exhibit non-linear response. These effects will tend to increase the variability of shaking within a zone, decrease the average difference in shaking between zones and decrease the certainty with which expected ground motions can be characterised. Also, near-source ground motions for an earthquake associated with a long fault rupture, such as Scenario 2, may be correlated with proximity to local asperities along the fault rupture, rather than proximity to the fault itself.

(9) The information given in this booklet and on the accompanying map is the result of a regional scale multi-disciplinary study of ground shaking hazard. The booklet and map provide useful information for the mitigation of ground shaking hazard in the Lower Hutt study area, but should not be used to replace site specific studies.

Detailed geological mapping, additional penetrometer probing, seismograph instrumentation, and topographic and mathematical modelling would resolve some of these issues.

4. SUMMARY

The geographic variation in ground shaking was defined using information from drillhole logs, microearthquake records, strong motion earthquake records, penetrometer logs and from numerical modelling. Four ground shaking hazard zone were established. These are Zone 1, Zone 2, Zone 3-4 and Zone 5. The geographic distribution of the zones is shown on the accompanying map.

Zone 1 areas are the least hazardous and are underlain by bedrock. Zone 2 areas show low to moderate amplification of earthquake shaking and are underlain by firm material. Zone 3-4 areas show moderate to high amplification of earthquake motions and are typically underlain by 5 to 10 metres of near-surface soft and/or loose material. Zone 5 areas show high to very high amplification of earthquake motion and are underlain by more than 10 metres of soft and/or loose material.

The expected response of each ground shaking hazard zone to two earthquake scenarios is given by Modified Mercalli intensity, peak ground acceleration, duration and amplification of ground motion parameters. The two parameters most easily understood are MM intensity and duration. For a large distant earthquake (Scenario 1), MM values range from V-VI in Zone 1, to VIII-IX in Zone 5. The response will range from *some alarm and damage* in Zone 1 areas to *general panic and substantial damage* in Zone 5 areas. Strong shaking will last for less than 5 seconds in Zone 1 areas, but continue for more than 15 seconds in Zone 5 areas. For a large earthquake centred on the Wellington Fault (Scenario 2), there is less difference between the zones, with strong shaking experienced everywhere. However, Zone 5 areas are expected to shake strongly for twice the duration of Zone 1 sites and to experience MM intensity 1 to 2 units higher on the scale.

Important assumptions that limit the certainty with which the ground shaking hazard zones can either be mapped or quantified must be considered when interpreting the hazard information.

APPENDICES

APPENDIX 1: CONTRIBUTING REPORTS AND REFERENCES

Hastie W J and Grindell D S (1991). Natural disaster reduction plan - seismic hazard: Summary report on work carried out in 1990/91. Technical Report LR1991/1, Policy and Planning Department, Wellington Regional Council.

Read S A L *et al* (1991). Wellington Regional Council regional natural hazard reduction plan: Geological setting of the Lower Hutt valley and Wainuiomata, including distribution of materials and geotechnical properties. DSIR Geology and Geophysics Contract Report CR91/045 (prepared for Wellington Regional Council).

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Stevens G (1991). On shaky ground: A geological guide to the Wellington metropolitan region. DSIR Geology and Geophysics and the Geological Society of New Zealand, Lower Hutt.

Van Dissen R J (1991). Ground shaking hazard map for the Lower Hutt and Porirua areas: A summary report. DSIR Geology and Geophysics Contract Report 1991/42 (prepared for Wellington Regional Council).

APPENDIX 2: GLOSSARY OF TECHNICAL TERMS

Active fault	A fault with evidence of surface movement in the last 50000 years or repeated surface movement in the last 500000 years.
g	Gravity. For an earthquake which produces a ground acceleration of 0.4g, the actual acceleration is 40 percent of gravity.
Hazard	A potentially damaging physical event.
Liquefaction	Process by which water-saturated sediment temporarily loses strength, usually because of strong shaking, and behaves as a fluid.
Quaternary	Geological time period spanning the last 2 million years.
Risk	The combination of a natural hazard event and our vulnerability to it. Risk can be specified in terms of expected number of lives lost, persons injured, damage to property, and disruption of economic activity due to a particular natural hazard.
Seiche	Oscillation of the surface of an enclosed body of water owing to earthquake shaking.
Seismicity	Ground shaking due to release of energy by earthquake.
Tsunami	An impulsively generated sea wave of local or distant origin that results from seafloor fault movement, large scale seafloor slides, or volcanic eruption on the seafloor.

APPENDIX 3: MODIFIED MERCALLI INTENSITY SCALE

MM 1 Not felt by humans except in especially favourable circumstances but birds and animals may be disturbed. Reported mainly from the upper floor of buildings more than 10 storeys high. Dizziness or nausea may be experienced. Branches of trees, chandeliers, doors and other suspended systems of long natural period may be seen to move slowly. Water in ponds, lakes and reservoirs may be set into seiche oscillation.

MM II Felt by few a persons at rest indoors, especially by those on upper floors or otherwise favourably placed. The long period effects listed under MM I may be more noticeable.

MM III Felt indoors but not identified as an earthquake by everyone. Vibration may be likened to the passing of light traffic. It may be possible to estimate the duration but not the direction. Hanging objects may swing slightly. Standing motorcars may rock slightly.

MM IV Generally noticed indoors but not outside. Very light sleepers may be wakened. Vibration may be likened to the passing of heavy traffic, or to the jolt of a heavy object falling or striking the building. Walls and frames of buildings are heard to creak. Doors and windows rattle. Glassware and crockery rattle. Liquids in open vessels may be slightly disturbed. Standing motorcars may rock and the shock can be felt by their occupants.

MM V Generally felt outside and by almost everyone indoors. Most sleepers awakened. A few people frightened. Direction of motion can be estimated. Small unstable objects are displaced or upset. Some glassware and crockery may be broken. Some windows cracked. A few earthenware toilet fixtures cracked. Hanging pictures move. Doors and shutters may swing. Pendulum clocks stop, start or change rate.

MM VI Felt by all. People and animals alarmed. Many run outside. Difficulty experienced in walking steadily. Slight damage to Masonry D. Some plaster cracks or falls. Isolated cases of chimney damage. Windows, glassware and crockery broken. Objects fall from shelves and pictures from walls. Heavy furniture overturned. Small church and school bells ring. Trees and bushes shake, or are heard to rustle. Loose material may be dislodged from existing slips, talus slopes, or shingle slides.

MM VII General alarm. Difficulty experienced in standing. Noticed by drivers of motorcars. Trees and bushes strongly shaken. Large bells ring. Masonry D cracked and damaged. A few instances of damage to Masonry C. Loose brickwork and tiles dislodged. Unbraced parapets and architectural ornaments may fall. Stone walls cracked. Weak chimneys broken, usually at the roofline. Domestic water tanks burst. Concrete irrigation ditches damaged. Waves seen on ponds and lakes. Water made turbid by stirred-up mud. Small slips and caving in of sand and gravel banks.

MM VIII Alarm may approach panic. Steering of motorcars affected. Masonry C damaged, with partial collapse. Masonry B damaged in some cases. Masonry A undamaged. Chimneys, factory stacks, monuments, towers and elevated tanks twisted or brought down. Panel walls thrown out of frame structures. Some brick veneers damaged. Decayed wooden piles broken. Frame houses not secured to the foundations may move. Cracks appear on steep slopes and in wet ground. Landslips in roadside cuttings and unsupported excavations.

Some tree branches may be broken off. Changes in the flow or temperature of springs and wells may occur. Small earthquake fountains may form.

MM IX General panic. Masonry D destroyed. Masonry C heavily damaged, sometimes collapsing completely. Masonry B seriously damaged. Frame structures racked and distorted. Damage to foundations general. Frame houses not secured to the foundations shifted off. Brick veneers fall and expose frames. Cracking of the ground conspicuous. Minor damage to paths and roadways. Sand and mud ejected in alleviated areas, with the formation of earthquake fountains and sand craters. Underground pipes broken. Serious damage to reservoirs.

MM X Most masonry structures destroyed, together with their foundations. Some well built wooden buildings and bridges seriously damaged. Dams, dykes and embankments seriously damaged. Railway lines slightly bent. Cement and asphalt roads and pavements badly cracked or thrown into waves. Large landslides on river banks and steep coasts. Sand and mud on beaches and flat land moved horizontally. Large and spectacular sand and mud fountains. Water from rivers, lakes and canals thrown up on banks.

MM XI Wooden frame structures destroyed. Great damage to railway lines and underground pipes.

MM XII Damage virtually total. Practically all works of construction destroyed or greatly damaged. Large rock masses displaced. Lines of sight and level distorted. Visible wave-motion of the ground surface reported. Objects thrown upwards into the air.

CATEGORIES OF NON-WOODEN CONSTRUCTION

Masonry A: Structures designed to resist lateral forces of about 0.1g, such as those satisfying the New Zealand Model Building Bylaws, 1955. Typical buildings of this kind are well reinforced by means of steel or ferro-concrete bands, or are wholly of ferro-concrete construction. All mortar is of good quality, and the design and workmanship is good. Few buildings erected prior to 1935 can be regarded as in Category A.

Masonry B: Reinforced buildings of good workmanship and with sound mortar but not designed in detail to resist lateral forces.

Masonry C: Buildings of ordinary workmanship, with mortar of average quality. No extreme weakness, such as inadequate bonding of the corners but neither designed nor reinforced to resist lateral forces.

Masonry D: Buildings with low standards of workmanship, poor mortar or constructed of weak materials like mud brick and rammed earth. Weak horizontally.

APPENDIX 4: GEOLOGICAL DESCRIPTIONS OF HAZARD ZONES

Zone 1: Bedrock. Moderately to very strong sandstone and siltstone (argillite), collectively referred to as *Greywacke*, also includes areas where bedrock is overlain by less than 10 metres of deeply weathered gravel and loess, or well engineered fill.

Zone 2: Alluvial gravel and fan alluvium; fine to coarse gravel, up to 200 metres thick, with some beds and lenses of finer grained sediment (sand, silt, clay and peat) usually less than 5 metres thick. The coarser sediments typically have moderate to high SPT values (20 to 60).

Zone 3-4: Up to 15 metres of fine grained sediment (fine sand, silt, clay and peat) within the top 20 metres or so of alluvial gravel, underlain by up to 250 metres of alluvial gravels and finer grained sediment. Near-surface fine grained sediments typically have low SPT values, less than 20, whereas the coarser consolidated sediments generally have moderate to high SPT values (20 to 60).

Zone 5: Soft sediment (fine sand, silt, clay and peat), 10 to 30 metres thick, at or very near the surface, underlain by bedrock or a variable thickness of gravel and other fine grained sediment. Shear wave velocities for these *flexible* sediments at Lower Hutt and Wainuiomata are in the order of 175 metres/second and 90 to 150 metres/second respectively.

GROUND SHAKING HAZARD
KAPITI

NOTES TO ACCOMPANY

SEISMIC HAZARD MAP SERIES: GROUND SHAKING HAZARD
MAP SHEET 5 KAPITI (FIRST EDITION) 1:40000

OCTOBER 1992

Publication WRC/PP-T-92/49

Compiled by

P A Kingsbury and W J Hastie

POLICY AND PLANNING DEPARTMENT

WELLINGTON REGIONAL COUNCIL

1. INTRODUCTION

1.1 BACKGROUND

The occurrence of earthquakes in the Wellington Region is inevitable due to its location at the boundary of two crustal plates. Earthquakes have the potential to cause significant adverse effects within the Region, including loss of life, injury, and social and economic disruption. In recognition of these potential effects, the Wellington Regional Council initiated a project in 1988 to:

* Assess the risks posed by earthquakes.
* Identify mitigation options.
* Implement measures to ensure that the level of risk is acceptable.

The first step in the project is to define the characteristics of the hazard. Information on the type and magnitude of possible effects, the probability of these occurring and the location of the effects within the Region is required. For the purposes of the project, *earthquake hazard* has been divided into a number of separate but interrelated components, including:

* Ground shaking.
* Surface fault rupture.
* Liquefaction and ground damage.
* Landsliding.
* Tsunami.

Although not all the effects will occur during every earthquake and many will be localised all components must be considered to obtain a complete picture of earthquake hazard.

1.2 PURPOSE OF MAP AND BOOKLET

A series of six map sheets, with accompanying booklets, has been compiled to describe the *ground shaking hazard* for the main metropolitan areas in the Region (refer to Index Map on accompanying map sheet):

* Sheet 1 - Wellington.
* Sheet 2 - Porirua and Tawa.
* Sheet 3 - Lower Hutt.
* Sheet 4 - Upper Hutt.
* Sheet 5 - Paekakariki, Paraparaumu, Waikanae and Otaki.
* Sheet 6 - Featherston, Greytown, Carterton and Masterton.

The purpose of the maps is to show the geographic variation in ground shaking hazard that could be expected during certain earthquake events. **The map sheets and booklets have been compiled from Wellington Regional Council reports and detailed reports prepared for the Wellington Regional Council by DSIR Geology and Geophysics, Land Resources and Physical Sciences, and Victoria University of Wellington. A list of the reports is given in Appendix 1.**

The intention of the map and booklet series is to raise public awareness of ground shaking hazard in the Wellington Region. The information will be useful to a range of potential users, including land use planners, civil defence organisations, land developers, engineers, utility operators, scientists and the general public.

Information on active faults in the western part of the Region has been published in a map series by the Wellington Regional Council - *Major Active Faults of the Wellington Region* (Map sheets 1, 2 and 3: 1991). Tsunami hazard information for Wellington Harbour is also available.

1.3 BOOKLET STRUCTURE

This booklet is divided into four main parts. Part 1 provides background information on the study. Part 2 outlines the hazard assessment approach and details the mapping methodology. Parameters used to quantify the hazard zones are also discussed. Part 3 states the assumptions and limitations that determine the certainty with which the hazard zones can either be mapped or quantified. A brief summary is given in Part 4.

Technical terms are defined in Appendix 2.

2. HAZARD ASSESSMENT

2.1 DATA SOURCES

The geographic variation in earthquake ground shaking was defined using geological and geotechnical information from microearthquake records, penetrometer logs, aerial photograph interpretation and field mapping. The shaking response of a representative suite of geological materials was assessed at 10 sites using records from 16 microearthquakes. The properties of the younger *flexible* materials were quantified using ten cone and two seismic-cone penetrometer probings.

2.2 EARTHQUAKE SCENARIOS

The Wellington Region is located across the boundary of the Pacific and Australian plates (Figure 1). As a consequence, the Region is cut by four major active faults and is frequently shaken by moderate to large earthquakes (Figures 2 and 3).

Because no single earthquake event adequately describes the potential ground shaking hazard in the Region two earthquake scenarios were used to define the hazard.

Scenario 1 is for a large, distant, shallow earthquake that produces Modified Mercalli intensity (MM) V-VI on bedrock (Appendix 3). It is expected that this type of earthquake will produce the largest variation in ground response. Scenario 1 implies minor damage to structures founded on the *best* sites and significant damage to certain structures on the *worst* sites. An example of such an event would be a Magnitude (M) 7 earthquake centred about 100 kilometres from the study area at a depth of less than 30 kilometres. Twenty years is a minimum estimate for the return time of a Scenario 1 event. This return time is derived from the historical occurrence of both large earthquakes and moderate sized local events. A maximum estimate is 80 years, which is the return time of MM VII or greater shaking at bedrock sites in the Wellington Region.

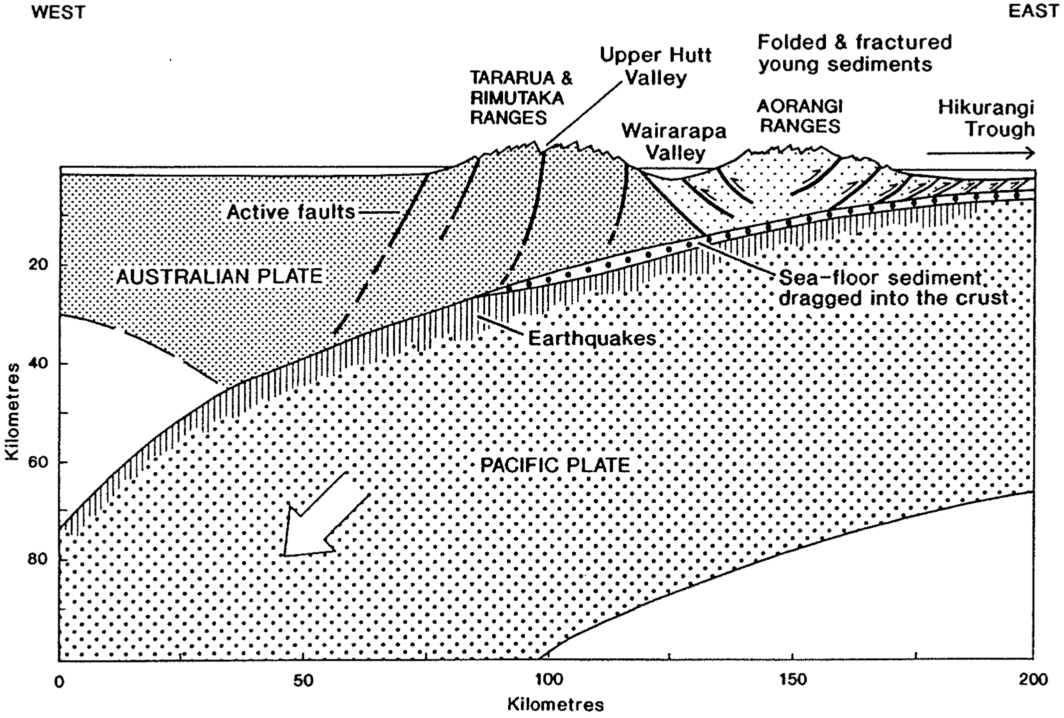

Figure 1: Source of earthquakes at plate boundary and along active faults. (After Stevens, 1991).

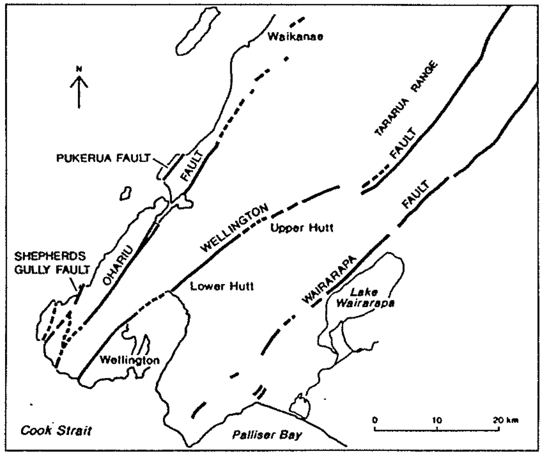

Figure 2: Active faults in the western part of the Wellington Region.

Scenario 2 is for a large earthquake centred on the Wellington-Hutt Valley segment of the Wellington Fault. Rupture of this segment is expected to be associated with a Magnitude 7.5 earthquake at a depth less than 30 kilometres, and up to 5 metres of horizontal and 1 metre vertical displacement at the ground surface. The return time for such an event is about 600 years and the probability of this event occurring in the next 30 years is estimated to be 10 percent. The values for near-source shaking resulting from a Scenario 2 earthquake are given with less certainty (refer to Section 2.5). This is because there are so few near-source ground motion data from large earthquakes, and factors such as proximity to local asperities along the rupture plane and random cancellation and reinforcement of seismic waves can locally suppress the effects caused by near-surface geological deposits. Furthermore, amplification of some local geological deposits will not occur at particular ground shaking frequencies and strengths.

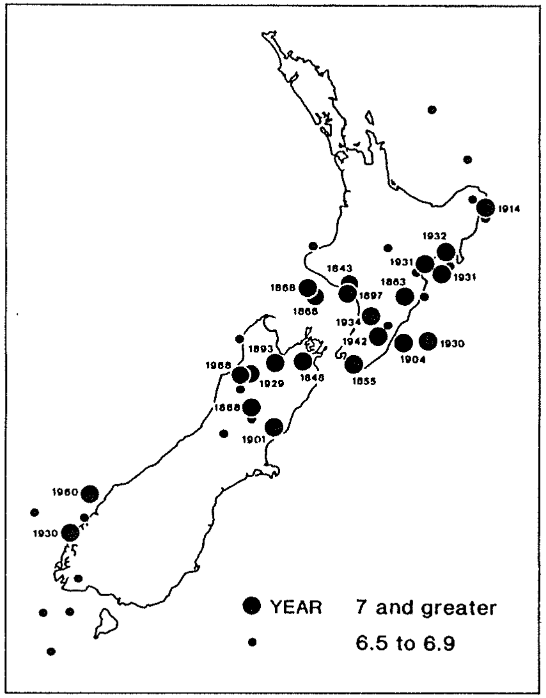

Figure 3: Epicentres of shallow earthquakes of magnitude 6.5 and greater since 1840. (After Van Dissen et al, 1992).

2.3 MAPPING METHODOLOGY

2.3.1 Surface geology

The distribution of geological materials was mapped at a scale of 1:25000. Fifteen geological units ranging from hard rock (*greywacke* and quartzite) to unconsolidated beach and peat deposits were mapped. The distribution of surface sediments in the Waikanae area is shown in Figure 4.

The map provides the geological base for the ground shaking hazard zones.

2.3.2 Weak ground motions

The microearthquake recording sites sampled a variety of geological ground conditions.

The relative shaking response of each site was expressed as an averaged ratio of the Fourier spectra of the seismograms compared to a reference bedrock site. The ratios are given as peak values within the 0.5 to 4 Hz frequency band. Relative to the reference bedrock site, the lowest ground motion amplifications were recorded at two sites underlain by compact sand and gravel (Pleistocene deposits). The peak Fourier spectral ratios were 3.1 and 4. The remaining seven sites were located on Postglacial loose silt, sand, fine gravel, and peat, and exhibit higher amplifications ranging from 7.5 to 21, relative to the reference site. In the Paraparaumu area shaking appears to increase towards the coast where sediment thickness is presumably greatest.

2.3.3 Penetrometer probings

The nature of the near-surface material at ten sites (Postglacial sediments) was further defined using cone and seismic-cone penetrometer probing (Figure 5). At all sites probing was stopped at less

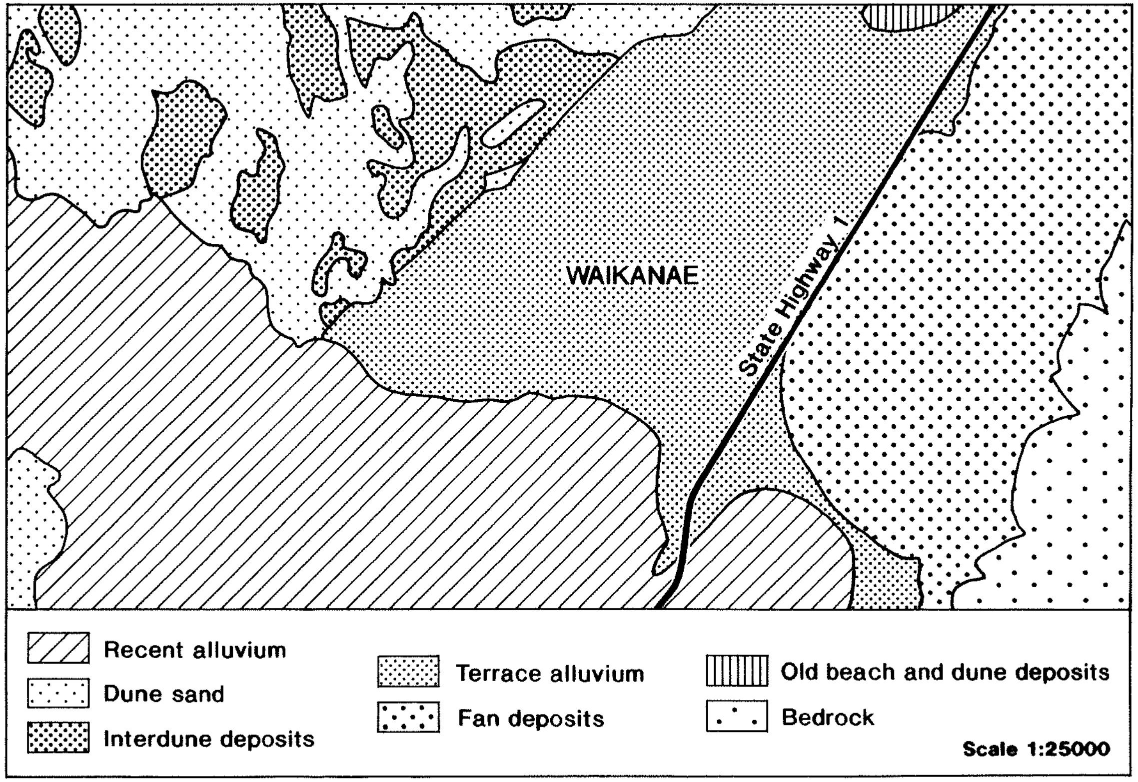

Figure 4: Sediment distribution in the Waikanae area. (After Heron and Van Dissen, 1992).

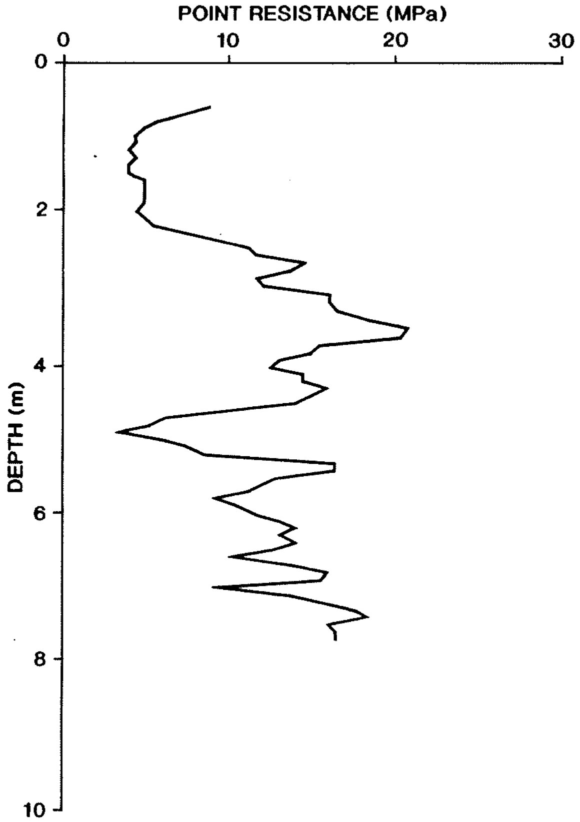

Figure 5: Cone penetrometer test results at Campbell Park, Paekakariki. (After Stephenson and Barker, 1992).

than 10 metres depth due to the inability of the cone to advance. The materials were generally loose to medium dense sand, and some peat and loose gravel. Shear wave velocities in the order of 130 to 200 metres/second were measured at two sites for the upper 5 to 10 metres. It is significant to note that during probing no reflected seismic energy was observed. This suggests that shear wave velocity gradually increases with depth, at least to a depth below which a reflected signal could not be detected, in the order of 15 metres.

2.3.4 **Ground shaking hazard zones**

Based on the distribution of geological materials and the measured response of these materials to seismic waves the Kapiti study area was mapped into three ground shaking hazard zones; Zone 1, Zone 2, and Zone 3-4 (refer to accompanying map sheet).

Zone 1, the least hazardous zone, is characteristically underlain by bedrock, and typically shows very low to low amplification of seismic waves.

Zone 2 areas are underlain by the *stiff* Pleistocene material, including compact gravel and sand interbedded with weaker silt and peat. Relative to Zone 1 low to moderate ground motion amplifications are expected in Zone 2.

Zone 3-4 areas are typically underlain by loose Postglacial material including geologically young beach and dune sand, river and fan alluvium, and peat. Moderate to high ground motion amplifications are anticipated in Zone 3-4 relative to Zone 1.

Figures 6 and 7 illustrate diagrammatically some of the relationships between the ground shaking hazard zones and the geology.

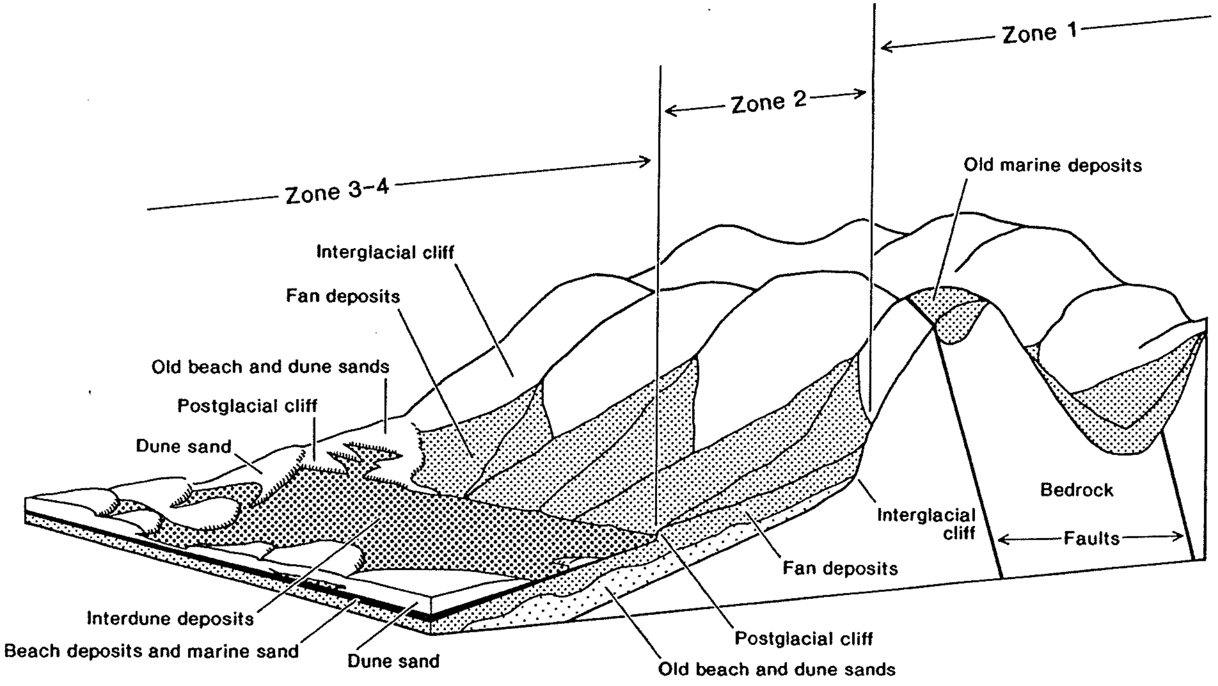

Figure 6: Block diagram showing the distribution of the main deposits on the Kapiti Coast. (After Heron and Van Dissen, 1992).

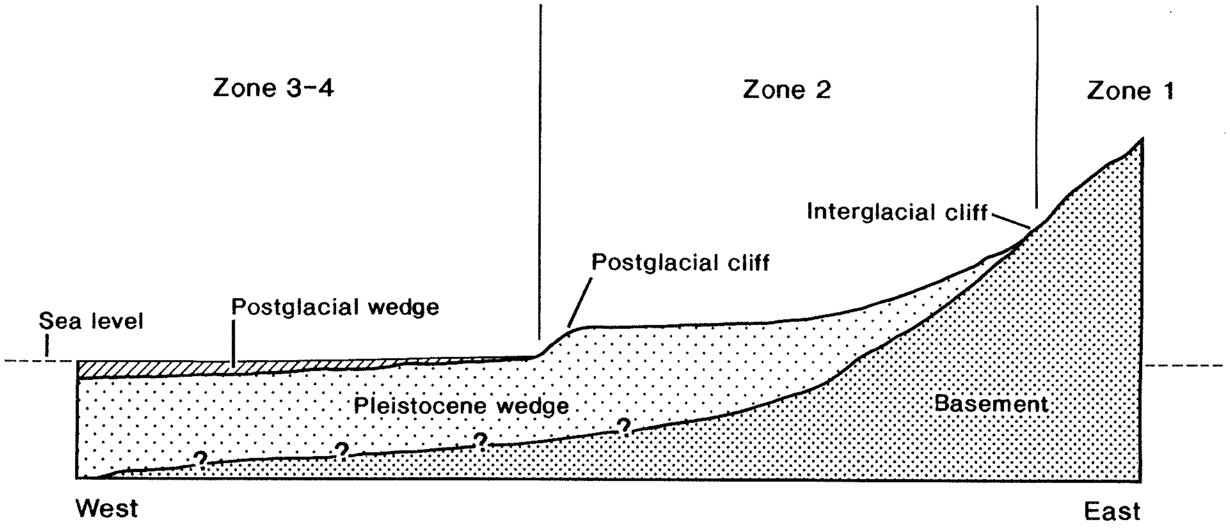

Figure 7: Diagrammatic cross section near Paraparaumu. (After Heron and Van Dissen, 1992).

Recent studies in both New Zealand and in California have found that the most *hazardous* site condition is typified by a greater than 10 metre thickness of geologically young (usually less than about 10000 years old), unconsolidated, often water saturated, fine-grained sediment with shear wave velocities in the order of 200 metres/second or less. These materials, often referred to as *soft soil* or *flexible sediment*, have the potential to greatly amplify earthquake ground shaking. Zone 3-4 materials in the Kapiti study area have near-surface shear wave velocities in the order of 200 metres/second or less. However, there does not appear to be any appreciable mappable extent of such materials with thicknesses greater than 10 metres. This contrasts with other parts of the Wellington Region, such as the low-relief coastal areas in Wellington, Lower Hutt, and Porirua that are typically underlain by thick *soft soil* or *flexible sediment*.

2.4 GEOLOGICAL DESCRIPTION OF HAZARD ZONES

Descriptions of the geological materials that typify each hazard zone are given in Appendix 4.

2.5 QUANTIFICATION OF HAZARD ZONES

The shaking response of the ground shaking hazard zones was assessed for the two earthquake scenarios (as described in Part 2.2). The response of each zone was expressed as a set of ground motion parameters, comprising:

- Expected Modified Mercalli intensity.
- Peak horizontal ground acceleration.
- Duration of strong shaking.
- Amplification of ground motion with respect to bedrock - expressed as a Fourier spectral ratio.

Some of these parameters were measured directly, others were estimated using comparisons found in the published scientific and engineering literature.

The Loma Prieta earthquake (1989, San Francisco) is significant to this study because of the recorded variations in ground motion related to local geological conditions and because the magnitude is similar to that expected for the Scenario 1 earthquake. Therefore, the values calculated for the ground motion parameters used in this study were compared with those measured for the Loma Prieta event.

2.5.1 Modified Mercalli intensity

Scenario 1: The Scenario 1 earthquake (a large, distant, shallow earthquake resulting in MM V-VI shaking on bedrock) will be of sufficient duration and contain sufficient long period energy to allow strong long period response to develop at sediment sites. The shallow focal depth will allow strong surface wave effects. The result will be a marked difference between the shaking of the *worst* sediment site and the *best* firm site. It is not uncommon during an earthquake to have a spread of three to four units of MM intensity separating the response of the *best* site from the response of a nearby *worst* site. However, it is again important to note that there does not appear to be an appreciable, mappable extent of thick (10 metres or more) near-surface *soft soil* or *flexible sediment* in the study area. Therefore a spread of three to four MM units, resulting from geographic variation in near-surface geology, is not anticipated for earthquakes impacting on the Kapiti Coast. The response of Zone 3-4 is expected to be in the order of one to two MM intensity units stronger than Zone 1. The Zone 2 response is expected to be one MM intensity unit stronger than Zone 1.

In terms of MM intensity the response of Zone 1 is expected to be MM V with some VI, Zone 2 is MM VI and Zone 3-4 is MM VI-VII (Table 1).

Scenario 2: The effects of a Scenario 2 event (a large, local Wellington Fault earthquake) will be a marked increase in the shaking throughout the Region relative to Scenario 1 and an increase in the variability of shaking within each zone, owing in part to differing source to site distances between the southern and northern part of the study area. In general, shaking decreases with increased distance from the source. Pukerua Bay is about 15 kilometres from the Wellington-Hutt Valley segment, Otaki is about 35 kilometres from the northern-most portion of the segment. Therefore sites near Otaki are expected to shake less than similar sites near Pukerua Bay. Ground shaking in Paraparaumu and Waikanae is expected to be intermediate between that of Pukerua Bay and Otaki.

SCENARIO 1

Zones	MM Intensity	Peak ground acceleration (g)	Duration	Amplification of ground motion (FSR)
1	V-VI	0.02-0.06	<5 sec	c. 1
2	VI	0.02-0.1	2-3x	<5x
3-4	VI-VII	0.02-0.1	2-3x	>5x, generally 8-15x

SCENARIO 2

Zones		MM Intensity	Peak ground acceleration (g)	Duration
1	Pukerua Bay	VIII	0.3-0.6	15-40 sec
	Otaki	VII	0.1-0.3	10-30 sec
2	Pukerua Bay	VIII-IX	0.3-0.6	1-2x
	Otaki	VII-VIII	0.1-0.3	1-2x
3-4	Pukerua Bay	IX-X		2x
	Otaki	VIII-IX		2x

Table 1: Ground motion parameters for the ground shaking hazard zones in the Kapiti area.

Epicentral intensities for the 1989 Loma Prieta earthquake were MM VIII. However, the Loma Prieta earthquake was smaller than the Scenario 2 event (M 7.1 compared to M 7.5). Epicentral intensities for similarly sized New Zealand earthquakes have been MM IX (1848 Marlborough), MM IX-X (1931 Hawkes Bay) and MM VIII-IX (1968 Inangahua).

On the basis of these relationships, MM VIII is expected in Zone 1 in the southern part of the study area (Table 1). Further from the Fault, near Otaki, MM VII is expected. In Zone 2, MM VIII to IX is expected near Pukerua Bay, and MM VII to VIII near Otaki. In Zone 3-4, MM IX to X is anticipated in the southern part of the study area, and MM VIII to IX in the northern part.

2.5.2 Peak horizontal ground acceleration

Scenario 1: Peak ground acceleration for Zone 1 is expected to be in the order of 0.02 to 0.06g. This compares to the 0.06g recorded during the Loma Prieta earthquake at a hard rock site 95 kilometres from the epicentre. Accelerations of 0.02 to 0.1g are expected in Zone 2 and Zone 3-4 (Table 1).

Scenario 2: The average peak ground accelerations expected for Scenario 2, based on a variety of attenuation relations and geological site considerations are Zone 1, Zone 2 and Zone 3-4, 0.3 to 0.6g near Pukerua Bay, and 0.1 to 0.3g near Otaki (Table 1).

2.5.3 Duration of strong shaking

Duration provides a qualitative estimate of the effects that local geological deposits can have in increasing the length of time a site will experience strong shaking. In general, amplitudes and durations of shaking increase with decreasing firmness of the underlying sediment. This has been observed in the Kapiti area for non-damaging earthquakes and elsewhere for larger damaging earthquakes. In this study, *duration* refers to the time between the first and last accelerations that exceed 0.05g.

Scenario 1: The expected duration of strong shaking in Zone 1 during a Scenario 1 event is less than 5 seconds (Table 1). The expected increase in duration, relative to bedrock, is 2 to 3 times in Zone 2 and Zone 3-4.

Scenario 2: Length of fault rupture is a controlling factor regarding the duration of near-source ground shaking. The Loma Prieta earthquake produced about 10 seconds of strong shaking, resulting from a 40 kilometres bilateral rupture (rupture propagation from the centre of the fault to the ends). Had the rupture been unilateral (rupture propagation from one end of the fault) the shaking would have lasted much longer, perhaps up to 20 seconds. Rupture of the Wellington Fault in Scenario 2 is expected to be about twice as long as the rupture that produced the Loma Prieta earthquake. The duration of shaking for Zone 1, close to Pukerua Bay, during Scenario 2 is expected to be 15 to 40 seconds, by comparison with the Loma Prieta event and depending on whether the rupture propagates bilaterally or unilaterally. Zone 1 shaking near Otaki is expected to be about 10 to 30 seconds. The anticipated increase in duration, relative to Zone 1, is 1 to 2 times for Zone 2 and 2 times for Zone 3-4 (Table 1).

2.5.4 **Amplification of ground motion spectrum**

Characteristic peak Fourier spectral ratios, within the frequency band of 0.5 to 4 Hz, are summarised in Table 1. Peak ratios vary from less than 5 for *stiff* sediment sites to greater than 20 for thick, loose sediment sites. The results are useful for determining relative shaking and for identifying the frequencies over which this shaking will be most strongly amplified during certain earthquakes, specifically Scenario 1 type events.

Ground motion amplification at most sites in the Kapiti study area occurred over a broad frequency band. Some Zone 3-4 sites exhibited a notable high frequency response. Two sites showed a narrow (resonant) frequency response at about 9 Hz. Resonant response appears most common when relatively thin (less than about 30 metres), *flexible*, low velocity sediment overlies much firmer material. The resonant frequency is a function of the thickness and velocity of the *flexible* layer. Site resonance is of most concern where built structures exist with natural periods that coincide with the resonant period band(s) of strong ground shaking. The resonant response in the above two cases was attributed to a thin (4 metres or less) layer of peat and silty sand. The lack of resonance at the other Kapiti sites probably indicates that the increase with depth of shear wave velocity and stiffness is gradual rather than occurring at an abrupt layer boundary.

Even though the ground motion amplifications measured in the Kapiti area were recorded during non-damaging earthquakes it is significant to note that intensity maps, prepared in the 1970's for the San Francisco Bay area, anticipated all of the areas that experienced high intensity shaking during the 1989 Loma Prieta earthquake. The level of amplification during even larger ground motions at near-source sites is unresolved. An amplification of near 20 at Paraparaumu is unlikely to persist to extreme motions because at high strain levels weak sediments begin to behave in a non-linear fashion - they begin to lose strength and increase wave attenuation or damping. This is particularly the case for the relatively non-cohesive Postglacial sediments. Nevertheless, variations in the nature of seismic response can still be expected from one zone to another. High amplification of small bedrock ground motions, such as the Scenario 1 bedrock motions, means that significant local damage at the *worst* sites in Zone 3-4 could result from an earthquake that would cause little or no damage in Zone 1. It is amplification of small bedrock ground motions that the measured spectral ratios best characterise, therefore they are given only for Scenario 1.

3. ASSUMPTIONS AND LIMITATIONS

Important assumptions that limit the certainty with which the ground shaking hazard zones can either be mapped or quantified are discussed below.

(1) Within each hazard zone there are isolated occurrences of materials that may cause ground motions that are not typical of the zone as a whole.

Along most of the Kapiti Coast the Postglacial cliff marks the boundary between Zone 2 and Zone 3-4. However, near Waikanae and north of Otaki sand derived from the Postglacial wedge has been blown up and over the Postglacial cliff and formed dunes on top of the Pleistocene wedge (Figure 7). The tallest dunes are 20 metres above the surrounding surface of the Pleistocene wedge. In places peat has formed between the dunes. Even though these geologically young deposits are east of the Postglacial cliff they are mapped as Zone 3-4. The position of the cliff in these cases is marked by a *dashed* line on the accompanying map. However, where these deposits are thin (less than 5 to 10 metres thick) their shaking response may be more typical of Zone 2.

The Waikanae and Otaki Rivers flow west across the Postglacial wedge. Coarse-grained channel deposits (gravel and sandy gravel) and finer-grained flood deposits (sand and silt) close to these rivers commonly form lenses within or a thin veneer (less than 5 metres thick) of alluvial sediment on top of the Postglacial wedge. The Postglacial wedge is primarily composed of beach and dune sand, and interdune peat, and the presence of thin alluvial deposits is not expected to alter the Zone 3-4 designation given to the Postglacial wedge. However, it is possible that in places the coarse-grained alluvial deposits are thick in the order of the thickness of the Postglacial wedge. In these cases the response to earthquake shaking may be more characteristic of Zone 2.

Potential significant variations in amplified resonant response over relatively short distances in some areas emphasise the importance of site specific studies to determine the nature and response of the materials at a site.

(2) High amplifications (greater than or equal to 20) have been recorded at Paraparaumu Beach, However, the spatial and subsurface distribution of the materials causing these amplifications is not well defined. This area has been mapped as Zone 3-4 because the presumed non-cohesive nature of the near-surface sediment at this site implies that high amplifications will not persist at high levels of shaking. If the sediment properties are not as presumed then high amplifications could occur at high levels of shaking and the area would be better mapped as a more hazardous zone, Zone 5.

(3) Near-surface shear wave velocities, including velocity profiles, for the geological materials in the Kapiti study area are not well known. Shear wave velocity is the parameter that best correlates with site amplification. Velocity profiles provide information regarding possible site resonance.

(4) Amplification of ground motion due to topographic effects has not been addressed for this study. Though probably localised, these effects can be pronounced.

(5) Near-surface geology is a primary factor influencing the relative level of earthquake shaking at a site. Earthquake source and path effects, including size of and distance from an earthquake, complexity of rupture, direction of rupture propagation, and possible crustal reflections can also play an important role. However, most of these factors are unique for every earthquake impacting on a site and are therefore difficult to characterise on a regional scale.

The subsurface distribution of sediment, including the shape, depth and type of sediment fill, can influence both the direction and frequency content of shaking at a site. It is not uncommon for sites within a sedimentary basin to show a marked directionality of response during earthquakes. Also, total sediment thickness, not just the physical properties of the near-surface sediments, can strongly influence the frequency band over which shaking is amplified. Deeper sediment sites tend to show broader band amplifications and stronger long period response. If the sediment of the coastal plain or part of the plain consistently responds strongly in certain directions then this information can be incorporated into the design and siting of built structures.

(6) Scenario 2 ground motion parameters are defined with less certainty. There is a worldwide lack of near-source ground motion data recorded during large earthquakes. During a large local earthquake, near-source seismic wave propagation will be complex and non-uniform, and ground strains will be large enough to cause some sediments to exhibit non-linear response. These effects will tend to increase the variability of shaking within a zone, decrease the average difference in shaking between zones and decrease the certainty with which expected ground motions can be characterised. Also, near-source ground motions for an earthquake associated with a long fault rupture, such as Scenario 2, may be correlated with proximity to local asperities along the fault rupture, rather than proximity to the fault itself.

(7) The information given in this booklet and on the accompanying map is the result of a regional scale multi-disciplinary study of ground shaking hazard. The booklet and map provide useful information for the mitigation of ground shaking hazard in the Kapiti study area but should not be used to replace site specific studies.

Detailed geological mapping, additional penetrometer probing, seismograph instrumentation, and topographic and mathematical modelling would resolve some of these issues.

4. SUMMARY

The geographic variation in ground shaking was defined using information from microearthquake records, penetrometer logs and aerial photograph interpretation. Three ground shaking hazard zones were established . These are Zone 1, Zone 2 and Zone 3-4. The geographic distribution of the zones is shown on the accompanying map.

Zone 1 areas are the least hazardous and are underlain by bedrock. Zone 2 areas show low to moderate amplification of earthquake shaking and are underlain by compact gravel and sand, interbedded with weaker silt and peat. These materials comprise the Pleistocene wedge. Zone 3-4 areas show moderate to high amplification of earthquake motions and are typically underlain by loose beach and dune sand, river and fan alluvium, and peat. These sediments comprise the Postglacial wedge.

The expected response of each ground shaking hazard zone to two earthquake scenarios is given by Modified Mercalli intensity, peak ground acceleration, duration and amplification of ground motion parameters. The two parameters most easily understood are MM intensity and duration. For a large distant earthquake (Scenario 1), MM values range from V-VI in Zone 1, to VI-VII in Zone 3-4. The response will range from *some alarm and damage* in Zone 1 areas to *general alarm and moderate damage* in Zone 3-4 areas. Strong shaking will last for less than 5 seconds in Zone 1 areas but continue for 10 to 15 seconds in Zone 3-4 areas. For a large earthquake centred on the Wellington Fault (Scenario 2) there is less difference between the zones, with strong shaking experienced everywhere.

In the Kapiti study area there does not appear to be extensive areas underlain by thick deposits of *soft soil* or *flexible sediment*. These materials, characteristic of the low relief, coastal areas of Wellington, Lower Hutt, and Porirua, are expected to most strongly amplify earthquake ground motions. Areas underlain by such materials are therefore subject to the greatest earthquake ground shaking hazard in the Wellington Region. The absence of these sorts of materials in the Kapiti study area implies that earthquake effects in the Kapiti area, particularly for Scenario 1 type events, may be less pronounced than in, for example, Wellington or Porirua.

Important assumptions that limit the certainty with which the ground shaking hazard zones can either be mapped or quantified exist and must be considered when interpreting the hazard information.

APPENDICES

APPENDIX 1: CONTRIBUTING REPORTS AND REFERENCES

Hastie W J (1992). Seismic hazard: Summary report on work carried out in 1991/92. Publication No. WRC/PP-T-92/23, Policy and Planning Department, Wellington Regional Council.

Heron D W and Van Dissen R J (1992). Geology of the Kapiti Coast (Pukerua Bay to Otaki), Wellington. DSIR Geology and Geophysics Contract Report 1992/19 (prepared for Wellington Regional Council).

Stephenson W R and Barker P R (1992). Report on cone penetrometer and seismic cone penetrometer probing in Wellington City, Kapiti Coast and Upper Hutt valley. DSIR Land Resources Contract Report 92/14 (prepared for Wellington Regional Council).

Stevens G (1991). On shaky ground: A geological guide to the Wellington metropolitan region. DSIR Geology and Geophysics and the Geological Society of New Zealand, Lower Hutt.

Taber J J and Richardson W (1992). Frequency dependent amplification of weak ground motions in Wellington City and the Kapiti Coast. Institute of Geophysics, Victoria University of Wellington (prepared for Wellington Regional Council).

Van Dissen R J *et al* (1992). Earthquake ground shaking hazard assessment for the Kapiti Coast, New Zealand. DSIR Geology and Geophysics Contract Report 1992/23 (prepared for Wellington Regional Council).

APPENDIX 2: GLOSSARY OF TECHNICAL TERMS

Active fault A fault with evidence of surface movement in the last 50000 years or repeated surface movement in the last 500000 years.

g Gravity. For an earthquake which produces a ground acceleration of 0.4g, the actual acceleration is 40 percent of gravity.

Hazard A potentially damaging physical event.

Liquefaction Process by which water-saturated sediment temporarily loses strength, usually because of strong shaking and behaves as a fluid.

Pleistocene The *Ice Age*. The period of time that lasted from about 2 million years ago to 10000 years ago.

Quaternary Geological time period spanning the last 2 million years.

Risk The combination of a natural hazard event and our vulnerability to it. Risk can be specified in terms of expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular natural hazard.

Seiche Oscillation of the surface of an enclosed body of water owing to earthquake shaking.

Seismicity Ground shaking due to release of energy by earthquake.

Tsunami An impulsively generated sea wave of local or distant origin that results from seafloor fault movement, large scale seafloor slides or volcanic eruption on the seafloor.

APPENDIX 3: MODIFIED MERCALLI INTENSITY SCALE

MM 1 Not felt by humans except in especially favourable circumstances but birds and animals may be disturbed. Reported mainly from the upper floor of buildings more than 10 storeys high. Dizziness or nausea may be experienced. Branches of trees, chandeliers, doors and other suspended systems of long natural period may be seen to move slowly. Water in ponds, lakes and reservoirs may be set into seiche oscillation.

MM II Felt by few a persons at rest indoors, especially by those on upper floors or otherwise favourably placed. The long period effects listed under MM I may be more noticeable.

MM III Felt indoors but not identified as an earthquake by everyone. Vibration may be likened to the passing of light traffic. It may be possible to estimate the duration but not the direction. Hanging objects may swing slightly. Standing motorcars may rock slightly.

MM IV Generally noticed indoors but not outside. Very light sleepers may be wakened. Vibration may be likened to the passing of heavy traffic, or to the jolt of a heavy object falling or striking the building. Walls and frames of buildings are heard to creak. Doors and windows rattle. Glassware and crockery rattle. Liquids in open vessels may be slightly disturbed. Standing motorcars may rock and the shock can be felt by their occupants.

MM V Generally felt outside and by almost everyone indoors. Most sleepers awakened. A few people frightened. Direction of motion can be estimated. Small unstable objects are displaced or upset. Some glassware and crockery may be broken. Some windows cracked. A few earthenware toilet fixtures cracked. Hanging pictures move. Doors and shutters may swing. Pendulum clocks stop, start or change rate.

MM VI Felt by all. People and animals alarmed. Many run outside. Difficulty experienced in walking steadily. Slight damage to Masonry D. Some plaster cracks or falls. Isolated cases of chimney damage. Windows, glassware and crockery broken. Objects fall from shelves and pictures from walls. Heavy furniture overturned. Small church and school bells ring. Trees and bushes shake, or are heard to rustle. Loose material may be dislodged from existing slips, talus slopes or shingle slides.

MM VII General alarm. Difficulty experienced in standing. Noticed by drivers of motorcars. Trees and bushes strongly shaken. Large bells ring. Masonry D cracked and damaged. A few instances of damage to Masonry C. Loose brickwork and tiles dislodged. Unbraced parapets and architectural ornaments may fall. Stone walls cracked. Weak chimneys broken, usually at the roofline. Domestic water tanks burst. Concrete irrigation ditches damaged. Waves seen on ponds and lakes. Water made turbid by stirred-up mud. Small slips and caving in of sand and gravel banks.

MM VIII Alarm may approach panic. Steering of motorcars affected. Masonry C damaged with partial collapse. Masonry B damaged in some cases. Masonry A undamaged. Chimneys, factory stacks, monuments, towers and elevated tanks twisted or brought down. Panel walls thrown out of frame structures. Some brick veneers damaged. Decayed wooden piles broken. Frame houses not secured to the foundations may move. Cracks appear on steep slopes and in wet ground. Landslips in roadside cuttings and unsupported excavations.

Some tree branches may be broken off. Changes in the flow or temperature of springs and wells may occur. Small earthquake fountains may form.

MM IX General panic. Masonry D destroyed. Masonry C heavily damaged, sometimes collapsing completely. Masonry B seriously damaged. Frame structures racked and distorted. Damage to foundations general. Frame houses not secured to the foundations shifted off. Brick veneers fall and expose frames. Cracking of the ground conspicuous. Minor damage to paths and roadways. Sand and mud ejected in alleviated areas, with the formation of earthquake fountains and sand craters. Underground pipes broken. Serious damage to reservoirs.

MM X Most masonry structures destroyed together with their foundations. Some well built wooden buildings and bridges seriously damaged. Dams, dykes and embankments seriously damaged. Railway lines slightly bent. Cement and asphalt roads and pavements badly cracked or thrown into waves. Large landslides on river banks and steep coasts. Sand and mud on beaches and flat land moved horizontally. Large and spectacular sand and mud fountains. Water from rivers, lakes and canals thrown up on banks.

MM XI Wooden frame structures destroyed. Great damage to railway lines and underground pipes.

MM XII Damage virtually total. Practically all works of construction destroyed or greatly damaged. Large rock masses displaced. Lines of sight and level distorted. Visible wave-motion of the ground surface reported. Objects thrown upwards into the air.

APPENDIX 4: GEOLOGICAL DESCRIPTIONS OF HAZARD ZONES

Zone 1: BEDROCK. Moderately strong to very strong quartzite, and sandstone and argillite (collectively referred to as *greywacke*). Also included are weak to moderately strong siltstone, sandstone, and greensand. These rocks are typically moderately weathered but in places are highly weathered. Rock defects are common and most closely spaced adjacent to major faults. Areas within Zone 1 are often overlain by less than 3 metres of scree, slopewash and loess.

Zone 2: STIFF SEDIMENT. Compact to very compact granular material composed primarily of Pleistocene gravel and sand. These materials are interbedded with weaker layers of silt and peat, and are collectively referred to as the Pleistocene wedge (Figure 7). The maximum sediment thickness beneath this zone is unknown but probably exceeds 100 metres in places.

Zone 3-4: LOOSE SEDIMENT. Loose to moderately dense granular material composed of geologically young (less than 6500 years old) beach and dune sand, and river and fan alluvium. Interdune peat, up to about 5 metres thick, is also present. Collectively these sediments comprise the Postglacial wedge (Figure 7) and have near-surface shear wave velocities in the order of 200 metres/second or less. From the Postglacial cliff these sediments almost certainly thicken to the west, towards the present-day coast. At Te Horo they are 40 metres thick.

GROUND SHAKING HAZARD
WAIRARAPA

NOTES TO ACCOMPANY

SEISMIC HAZARD MAP SERIES: GROUND SHAKING HAZARD MAP SHEET 6 WAIRARAPA (FIRST EDITION) 1:50000

OCTOBER 1992

Publication WRC/PP-T-92/50

Compiled by

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POLICY AND PLANNING DEPARTMENT

WELLINGTON REGIONAL COUNCIL

1. INTRODUCTION

1.1 BACKGROUND

The occurrence of earthquakes in the Wellington Region is inevitable due to its location at the boundary of two crustal plates. Earthquakes have the potential to cause significant adverse effects within the Region, including loss of life, injury, and social and economic disruption. In recognition of these potential effects, the Wellington Regional Council initiated a project in 1988 to:

- Assess the risks posed by earthquakes.
- Identify mitigation options.
- Implement measures to ensure that the level of risk is acceptable.

The first step in the project is to define the characteristics of the hazard. Information on the type and magnitude of possible effects, the probability of these occurring and the location of the effects within the Region is required. For the purposes of the project *earthquake hazard* has been divided into a number of separate but interrelated components, including:

- Ground shaking.
- Surface fault rupture.
- Liquefaction and ground damage.
- Landsliding.
- Tsunami.

Although not all the effects will occur during every earthquake, and many will be localised, all components must be considered to obtain a complete picture of earthquake hazard.

1.2 PURPOSE OF MAP AND BOOKLET

A series of six map sheets, with accompanying booklets, has been compiled to describe the *ground shaking hazard* for the main metropolitan areas in the Region (refer to Index Map on accompanying map sheet):

- Sheet 1 - Wellington.
- Sheet 2 - Porirua and Tawa.
- Sheet 3 - Lower Hutt.
- Sheet 4 - Upper Hutt.
- Sheet 5 - Paekakariki, Paraparaumu, Waikanae and Otaki.
- Sheet 6 - Featherston, Greytown, Carterton and Masterton.

The purpose of the maps is to show the geographic variation in ground shaking hazard that could be expected during certain earthquake events. **The map sheets and booklets have been compiled from Wellington Regional Council reports and detailed reports prepared for the Wellington Regional Council by DSIR Geology and Geophysics, Land Resources and Physical Sciences, and Victoria University of Wellington. A list of the reports is given in Appendix 1.**

The intention of the map and booklet series is to raise public awareness of ground shaking hazard in the Wellington Region. The information will be useful to a range of potential users, including land use planners, civil defence organisations, land developers, engineers, utility operators, scientists and the general public.

Information on active faults in the western part of the Region has been published in a map series by the Wellington Regional Council - *Major Active Faults of the Wellington Region* (Map sheets 1,2 and 3: 1991). Tsunami hazard information for Wellington Harbour is also available.

1.3 BOOKLET STRUCTURE

This booklet is divided into four main parts. Part 1 provides background information on the study. Part 2 outlines the hazard assessment approach and the mapping methodology. Parameters used to quantify the hazard zones are also discussed. Part 3 states the assumptions and limitations that determine the certainty with which the hazard zones can either be mapped or quantified. A brief summary is given in Part 4.

Technical terms are defined in Appendix 2.

2. HAZARD ASSESSMENT

2.1 DATA SOURCES

The geographic variation in earthquake ground shaking for the Wairarapa study area was based on previously established correlations between near-surface geological materials and their capability for amplifying earthquake ground motions.

2.2 EARTHQUAKE SCENARIOS

The Wellington Region is located across the boundary of the Pacific and Australian plates (Figure 1). As a consequence, the Region is cut by four major active faults and is frequently shaken by moderate to large earthquakes (Figures 2 and 3).

Because no single earthquake event adequately describes the potential ground shaking hazard in the Region two earthquake scenarios were used to define the hazard.

Scenario 1 is a large, distant, shallow earthquake that produces Modified Mercalli intensity (MM) V-VI in bedrock over the Wairarapa area (Appendix 3). An example of such an event would be a Magnitude (M) 7 earthquake centred about 100 kilometres from the study area at a depth of 15 to 60 kilometres.

Scenario 2 is for a large earthquake centred on the Wellington-Hutt Valley segment of the Wellington Fault. Rupture of this segment is expected to be associated with a Magnitude 7.5 earthquake at a depth less than 30 kilometres, and up to 5 metres of horizontal and 1 metre vertical displacement at the ground surface. The return time for such an event is about 600 years and the probability of this event occurring in the next 30 years is estimated to be 10 percent.

The values for near-source shaking resulting from a Scenario 2 earthquake are given with less certainty (refer to Section 2.4). This is because there are so few near-source ground motion data from large earthquakes, and factors such as proximity to local asperities along the rupture plane and random cancellation and reinforcement of seismic waves can locally suppress the effects caused by near-surface geological deposits. Furthermore, amplification of some local geological deposits will not occur at particular ground shaking frequencies and strengths.

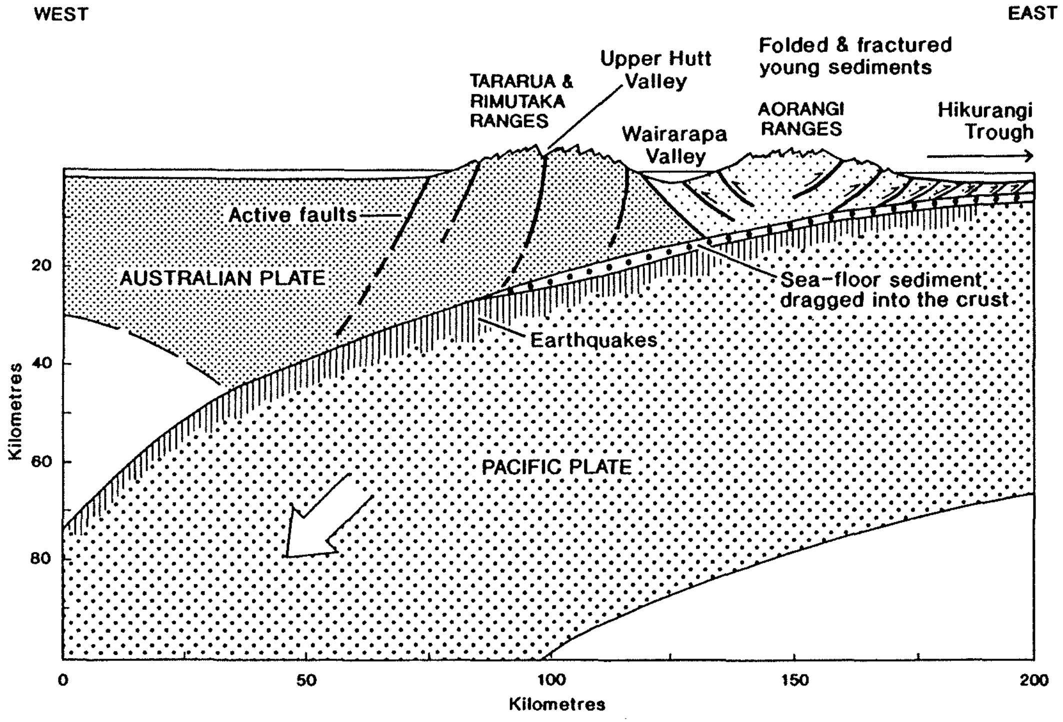

Figure 1: Source of earthquakes at plate boundary and along active faults. (After Stevens, 1991).

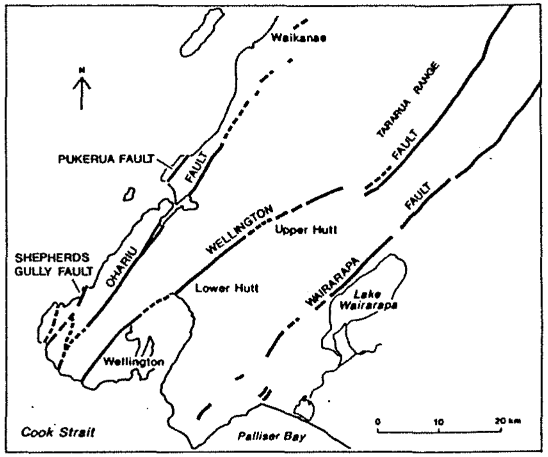

Figure 2: Active faults in the western part of the Wellington Region.

2.3 GROUND SHAKING HAZARD ZONES

Based on the distribution of geological materials the Wairarapa study area was mapped into two ground shaking hazard zones; Zone 1 and Zone 2-4 (refer to accompanying map sheet). Areas in the Wellington Region underlain by significant thicknesses (greater than 10 metres) of *soft soil* or *flexible sediment* are mapped as Zone 5 and are expected to have a high to very high amplification capability. No Zone 5 areas were mapped in the Wairarapa study area.

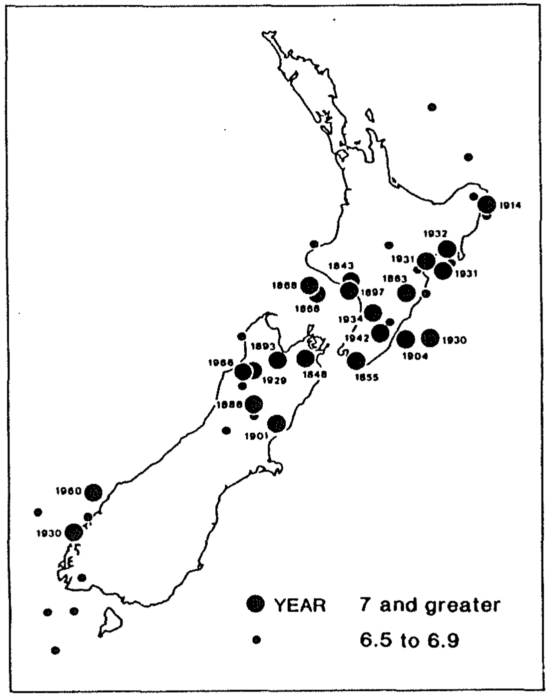

Figure 3: Epicentres of shallow earthquakes of magnitude 6.5 and greater since 1840 (after Van Dissen, 1992).

Areas directly underlain by weak to strong rock, with little or no cover, are mapped as Zone 1. This includes areas underlain by weathered greywacke. Zone 1 areas are expected to have an intermediate to very low amplification capability.

Areas underlain by greater than about 10 metres of Holocene and Pleistocene gravel and sand, and very weak rock are expected to have an intermediate ground shaking response compared to Zones 1 and 5. These areas are mapped as Zone 2-4 and are expected to have an intermediate to high amplification capability. The geological deposits mapped as Zone 2-4 in the Wairarapa study area encompass a wide range of grain sizes and sediment thicknesses. Zone 2-4 includes much of the Wairarapa valley floor and the gentle hill country.

2.4 QUANTIFICATION OF HAZARD ZONES

The shaking response of the ground shaking hazard zones was assessed for the two earthquake scenarios (as described in Part 2.2). The response of each zone was expressed as a set of ground motion parameters, comprising:

- * Expected Modified Mercalli intensity.
- * Peak horizontal ground acceleration.
- * Duration of strong shaking.
- * Amplification of ground motion with respect to bedrock - expressed as a Fourier spectral ratio.

These parameters were estimated using comparisons found in the published scientific and engineering literature, and from other work in the Wellington Region.

The Loma Prieta earthquake (1989, San Francisco) is significant to this study because of the recorded variations in ground motion related to local geological conditions and because the magnitude is similar to that expected for the Scenario 1 earthquake. Therefore, the values calculated for the ground motion parameters used in this study were compared with those measured for the Loma Prieta event.

2.4.1 **Modified Mercalli intensity**

Scenario 1: The Scenario 1 earthquake (a large, distant, shallow earthquake, resulting in MM V-VI shaking on bedrock) will be of sufficient duration and contain sufficient long period energy to allow strong long-period response to develop at sediment sites. The shallow focal depth will allow strong surface wave effects. The result will be a marked difference between the shaking of the *worst* sediment site and the *best* rock site. It is not uncommon during an earthquake to have a spread of three to four units of MM intensity separating the response of the *best* site from the response of a nearby *worst* site. However, it is again important to note that there does not appear to be an appreciable mappable extent of near-surface *soft soils* or *flexible sediments* in the Wairarapa. The response of Zone 2-4 is expected to be in the order of one MM intensity unit stronger than Zone 1.

Therefore, in terms of MM intensity the response of Zone 1 is expected to be MM V with some VI and Zone 2-4 is MM VI with some VII (Table 1).

Scenario 2: The effects of a Scenario 2 event (a large, local Wellington Fault earthquake) will be a marked increase in the shaking throughout the study area, relative to Scenario 1, and an increase in the variability of shaking within each zone, owing in part to differing source to site distances between the southern and northern parts of the study area. In general, shaking decreases with increasing distance from the source. Featherston is about 10 kilometres from the Wellington-Hutt Valley segment of the Wellington Fault, Masterton is about 40 kilometres from the northernmost portion of the segment. Therefore, sites near Masterton are expected to shake less than similar sites near Featherston. The shaking in Martinborough, Greytown and Carterton is expected to be intermediate between that of Featherston and Masterton.

Epicentral intensities for the 1989 Loma Prieta earthquake were MM VIII. However, the Loma Prieta earthquake was smaller than the Scenario 2 event (M 7.1 compared to M 7.5). Epicentral

Scenario 1				
Zones	MM Intensity	Peak ground acceleration (g)	Duration	Amplification of ground motion (FSR)
1	V-VI	0.02-0.06	<5 sec	1-3x
2-4	VI-VII	0.02-0.1	2-3x	2-10x

Scenario 2				
Zones		MM Intensity	Peak ground acceleration (g)	Duration
1	Featherston	VIII	0.3-0.6	15-40 sec
	Masterton	VII	0.1-0.3	10-30 sec
2-4	Featherston	VIII-IX	0.3-0.6	1-2x
	Masterton	VII-VIII	0.1-0.3	1-2x

Table 1: Ground motion parameters for the ground shaking hazard zones in the Wairarapa area.

intensities for similarly sized New Zealand earthquakes have been MM IX (1848 Marlborough), MM IX-X (1931 Hawkes Bay) and MM VIII-IX (1968 Inangahua).

On the basis of these relationships, MM VIII is expected in Zone 1 in the western part of the study area (Table 1). Further from the Fault, near Masterton, MM VII is expected. MM VIII-IX is expected in Zone 2-4 near Featherston, and MM VII-VIII further away, near Masterton.

2.4.2 **Peak horizontal ground acceleration**

Scenario 1: Peak ground acceleration for Zone 1 is expected to be in the order of 0.02 to 0.06g. This compares to the 0.06g recorded during the Loma Prieta earthquake at a hard rock site 95 kilometres from the epicentre. Accelerations of 0.02 to 0.1g are expected in Zone 2-4 (Table 1).

Scenario 2: The average peak ground accelerations expected for Scenario 2, based on a variety of attenuation relations and geological site considerations are: Zone 1, 0.3 to 0.6g near Featherston, and 0.1 to 0.3g near Masterton; Zone 2-4, 0.3 to 0.6g near Featherston, and 0.1 to 0.3g near Masterton (Table 1).

2.4.3 **Duration of strong shaking**

Duration provides a qualitative estimate of the effects that local geological deposits can have in increasing the length of time a site will experience strong shaking. In general, amplitudes and durations of shaking increase with decreasing firmness of the underlying sediment. This has been observed in the Wellington Region for non-damaging earthquakes and elsewhere for larger damaging earthquakes. In this study, *duration* refers to the time between the first and last accelerations that exceed 0.05g.

Scenario 1: The expected duration of strong shaking in Zone 1 during a Scenario 1 event is less than 5 seconds (Table 1). The expected increase in duration, relative to bedrock, is 2 to 3 times in Zone 2-4.

Scenario 2: Length of fault rupture is a controlling factor regarding the duration of near-source ground shaking. The Loma Prieta earthquake produced about 10 seconds of strong shaking, resulting from a 40 kilometres bilateral rupture (rupture propagation from the centre of the fault to the ends). Had the rupture been unilateral (rupture propagation from one end of the fault) the shaking would have lasted much longer, perhaps up to 20 seconds. Rupture of the Wellington Fault in Scenario 2 is expected to be about twice as long as the rupture that produced the Loma Prieta earthquake. The duration of shaking for Zone 1, close to Featherston, during Scenario 2 is expected to be 15 to 40 seconds, by comparison with the Loma Prieta event and depending on whether the rupture propagates bilaterally or unilaterally. Zone 1 shaking near Masterton is expected to be in the order of 10 to 30 seconds. The anticipated increase in duration for Zone 2-4, relative to Zone 1, is 1 to 2 times (Table 1).

2.4.4 Amplification of ground motion spectrum

Characteristic peak Fourier spectral ratios, within the frequency band of 0.5 to 4 Hz, are summarised in Table 1. The results are useful for determining relative shaking and for identifying the frequencies over which this shaking will be most strongly amplified during certain earthquakes, specifically Scenario 1 type events.

Based on a comparison between the geological materials (and their amplification characteristics) present elsewhere in the Region with those in the Wairarapa study area, the following inferences are made regarding amplification of ground motions in the Wairarapa. During a Scenario 1 type event, Zone 1 areas are expected to experience amplifications of less than 3 (excluding locally significant topography related amplifications) and Zone 2-4 areas are expected to experience amplifications of 2 to 10.

Even though the ground motion amplifications measured elsewhere in the Wellington Region were recorded during non-damaging earthquakes it is significant to note that intensity maps, prepared in the 1970's for the San Francisco Bay area, anticipated all of the areas that experienced high intensity shaking during the 1989 Loma Prieta earthquake. The level of amplification during even larger ground motions at near-source sites is unresolved. An amplification of FSR greater than 5 is unlikely to persist to extreme motions. This is because at high strain levels weak sediments begin to behave in a nonlinear fashion - they begin to lose strength and increase wave attenuation or damping. Nevertheless, variations in the nature of seismic response can still be expected from one zone to another. High amplification of small bedrock ground motions, such as the Scenario 1 bedrock motions, means that significant local damage in Zone 5 could result from an earthquake that would cause little or no damage in Zone 1. Amplification of small bedrock ground motions are best characterised by measured spectral ratios and are therefore given only for Scenario 1.

3. ASSUMPTIONS AND LIMITATIONS

Important assumptions that limit the certainty with which the ground shaking hazard zones can either be mapped or quantified are discussed below.

(1) The single most noticeable factor limiting the certainty of the zonation presented in this report is that no earthquake ground motions have been measured in the Wairarapa study area. The ground motion response of the near-surface geological materials in the Wairarapa is inferred based on the measured response of similar materials in New Zealand and overseas. The high degree of compatibility between the ground motion amplifications reported in other parts of the Wellington Region with those from overseas, for similar geological materials, gives confidence that the Wairarapa ground shaking zonation is realistic.

(2) Within each hazard zone there are isolated occurrences of materials that may cause ground motions that are not typical of the zone as a whole. The hill country in the Wairarapa is composed of several different rock types that are expected to have a range of shear-wave velocities. In the hill areas it is expected that there will be a complex interaction between amplifications caused by topography and those caused by variations in local geology, including weathering profile. Parts of what is mapped as Zone 2-4 in the Wairarapa study area are underlain by near-surface layers of peat and alluvial silt. Usually these layers are thin, two metres or less. However, if they are about 10 metres thickness or more a response less favourable than that anticipated for Zone 2-4 is expected. Areas where an appreciable thickness of these fine-grained materials may exist include the ponded region immediately northwest from the Waingawa freezing works site and the abandoned meander channels along the course of the Ruamahanga River. Also, the former extent of Lake Wairarapa presents an unresolved question regarding the possible occurrence of near-surface fine-grained lake sediments in the southwestern-most part of the study area (the Murphys Line/South Featherston Road area).

Significant variations in amplified resonant response over relatively short distances in some areas emphasise the importance of site specific studies to determine the nature and response of the materials at a site.

(3) Near-surface shear wave velocities for the geological materials in the Wairarapa study area are not known. Therefore, direct comparisons between shear wave velocity and ground motion amplification is not possible. The ability to correlate geological material with amplification capability is therefore limited. This is specifically the case regarding the ground shaking hazard classification of the mid-Quaternary compact gravels and sands that directly underlie Bidwell hill, the southeastern border of the

study area and the hill northeast from Masterton marked by Owaka South trig. At present, areas underlain by these materials are mapped as Zone 2-4. Additional studies could find that they are better classified as Zone 1.

(4) Amplification of ground motion due to topographic effects has not been addressed for this study. Though probably localised, these effects can be pronounced.

(5) Scenario 2 ground motion parameters are defined with less certainty. There is a worldwide lack of near-source ground motion data recorded during large earthquakes. During a large local earthquake near-source seismic wave propagation will be complex and non-uniform, and ground strains will be large enough to cause some sediments to exhibit non-linear response. These effects will tend to increase the variability of shaking within a zone, decrease the average difference in shaking between zones and decrease the certainty with which expected ground motions can be characterised. Also, near-source ground motions for an earthquake associated with a long fault rupture, such as Scenario 2, may be correlated with proximity to local asperities along the fault rupture, rather than proximity to the fault itself.

(6) Near-surface geology is a primary factor influencing the relative level of earthquake shaking at a site. Earthquake source and path effects, including size of and distance from an earthquake, complexity of rupture, direction of rupture propagation and possible crustal reflections, can play an important role. However, these factors are rather unique for every earthquake impacting on a site and are therefore difficult to characterise on a regional scale.
Basin geometry, including the depth and type of basin fill, can influence both the direction and frequency content of shaking within the basin. It is not uncommon for sites within a sedimentary basin, such as the Wairarapa depression, to show a marked directionality of response during earthquakes. Also, total sediment thickness, not just the physical properties of the near-surface sediments, can influence the frequency band over which shaking is amplified. Deeper sediment sites tend to show broader band amplifications and stronger long period response compared to sites underlain by a relatively simple, thin (about 10 to 30 metres thick) layer of soft, unconsolidated, fine-grained sediment. If the basin, or an area within a basin consistently responds strongly in certain directions or consistently amplifies ground motions within a certain frequency band, then this information can be incorporated into the design and siting of built structures.

(7) The information given in this booklet and on the accompanying map is the result of a regional scale multi-disciplinary study of ground shaking hazard. The booklet and map provide useful information for the mitigation of ground shaking hazard in the Wairarapa study area but should not be used to replace site specific studies.

Detailed geological mapping including compilation of existing drillhole data, penetrometer probing, seismograph instrumentation, and topographic and mathematical modelling would resolve some of these issues.

4. SUMMARY

The geographic variation in ground shaking was based on previously established correlations between near-surface geological materials and their capability for amplifying earthquake ground motions. Two ground shaking hazard zones were identified in the Wairarapa study area. These are Zone 1 and Zone 2-4. During damaging earthquakes Zone 2-4 is expected to experience, on average, greater levels of shaking than Zone 1. The geographic distribution of the zones is shown on the accompanying map.

The expected response of the two ground shaking hazard zones to two earthquake scenarios is given by Modified Mercalli intensity, peak ground acceleration, duration, and amplification of ground motion parameters.

In the Wairarapa study area there do not appear to be extensive areas of *soft soils* or *flexible sediments*. These materials, characteristic of the low-relief coastal areas of Wellington, Lower Hutt and Porirua, are expected to strongly amplify earthquake ground motions. Therefore, areas underlain by such materials are subject to the greatest earthquake ground shaking in the Wellington Region and are mapped as Zone 5. The absence of these materials in the Wairarapa study area suggests that earthquake effects in the study area will be less pronounced than in, for example, Wellington or Porirua.

Important assumptions that limit the certainty with which the ground shaking hazard zones can either be mapped or quantified exist and must be considered when interpreting the hazard information.

APPENDICES

APPENDIX 1: CONTRIBUTING REPORTS AND REFERENCES

Hastie W J (1992). Seismic hazard: Summary report on work carried out in 1991/92. Publication No. WRC/PP-T-92/23, Policy and Planning Department, Wellington Regional Council.

Stevens G (1991). On shaky ground: A geological guide to the Wellington metropolitan region. DSIR Geology and Geophysics and the Geological Society of New Zealand, Lower Hutt.

Van Dissen R J (1992). Earthquake ground shaking hazard assessment of the Wairarapa, New Zealand. DSIR Geology and Geophysics Contract Report 1992/10 (prepared for Wellington Regional Council).

APPENDIX 2: GLOSSARY OF TECHNICAL TERMS

Active fault A fault with evidence of surface movement in the last 50000 years or repeated surface movement in the last 500000 years.

g Gravity. For an earthquake which produces a ground acceleration of 0.4g, the actual acceleration is 40 percent of gravity.

Hazard A potentially damaging physical event.

Holocene The last 10000 years.

Liquefaction Process by which water-saturated sediment temporarily loses strength, usually because of strong shaking and behaves as a fluid.

Pleistocene The *Ice Age*. The period of time that lasted from about 2 million years ago to 10000 years ago.

Quaternary Geological time period spanning the last 2 million years.

Risk The combination of a natural hazard event and our vulnerability to it. Risk can be specified in terms of expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular natural hazard.

Seiche Oscillation of the surface of an enclosed body of water owing to earthquake shaking.

Seismicity Ground shaking due to release of energy by earthquake.

Tsunami An impulsively generated sea wave of local or distant origin that results from seafloor fault movement, large scale seafloor slides or volcanic eruption on the seafloor.

APPENDIX 3: MODIFIED MERCALLI INTENSITY SCALE

MM 1 Not felt by humans, except in especially favourable circumstances but birds and animals may be disturbed. Reported mainly from the upper floor of buildings more than 10 storeys high. Dizziness or nausea may be experienced. Branches of trees, chandeliers, doors and other suspended systems of long natural period may be seen to move slowly. Water in ponds, lakes and reservoirs may be set into seiche oscillation.

MM II Felt by few a persons at rest indoors, especially by those on upper floors or otherwise favourably placed. The long period effects listed under MM I may be more noticeable.

MM III Felt indoors but not identified as an earthquake by everyone. Vibration may be likened to the passing of light traffic. It may be possible to estimate the duration but not the direction. Hanging objects may swing slightly. Standing motorcars may rock slightly.

MM IV Generally noticed indoors but not outside. Very light sleepers may be wakened. Vibration may be likened to the passing of heavy traffic, or to the jolt of a heavy object falling or striking the building. Walls and frames of buildings are heard to creak. Doors and windows rattle. Glassware and crockery rattle. Liquids in open vessels may be slightly disturbed. Standing motorcars may rock and the shock can be felt by their occupants.

MM V Generally felt outside and by almost everyone indoors. Most sleepers awakened. A few people frightened. Direction of motion can be estimated. Small unstable objects are displaced or upset. Some glassware and crockery may be broken. Some windows cracked. A few earthenware toilet fixtures cracked. Hanging pictures move. Doors and shutters may swing. Pendulum clocks stop, start or change rate.

MM VI Felt by all. People and animals alarmed. Many run outside. Difficulty experienced in walking steadily. Slight damage to Masonry D. Some plaster cracks or falls. Isolated cases of chimney damage. Windows, glassware and crockery broken. Objects fall from shelves and pictures from walls. Heavy furniture overturned. Small church and school bells ring. Trees and bushes shake, or are heard to rustle. Loose material may be dislodged from existing slips, talus slopes or shingle slides.

MM VII General alarm. Difficulty experienced in standing. Noticed by drivers of motorcars. Trees and bushes strongly shaken. Large bells ring. Masonry D cracked and damaged. A few instances of damage to Masonry C. Loose brickwork and tiles dislodged. Unbraced parapets and architectural ornaments may fall. Stone walls cracked. Weak chimneys broken, usually at the roofline. Domestic water tanks burst. Concrete irrigation ditches damaged. Waves seen on ponds and lakes. Water made turbid by stirred-up mud. Small slips and caving in of sand and gravel banks.

MM VIII Alarm may approach panic. Steering of motorcars affected. Masonry C damaged, with partial collapse. Masonry B damaged in some cases. Masonry A undamaged. Chimneys, factory stacks, monuments, towers and elevated tanks twisted or brought down. Panel walls thrown out of frame structures. Some brick veneers damaged. Decayed wooden piles broken. Frame houses not secured to the foundations may move. Cracks appear on steep slopes and in wet ground. Landslips in roadside cuttings and unsupported excavations. Some tree branches may be broken off. Changes in the flow or temperature of springs and wells may occur. Small earthquake fountains may form.

MM IX General panic. Masonry D destroyed. Masonry C heavily damaged, sometimes collapsing completely. Masonry B seriously damaged. Frame structures racked and distorted. Damage to foundations general. Frame houses not secured to the foundations shifted off. Brick veneers fall and expose frames. Cracking of the ground conspicuous. Minor damage to paths and roadways. Sand and mud ejected in alleviated areas, with the formation of earthquake fountains and sand craters. Underground pipes broken. Serious damage to reservoirs.

MM X Most masonry structures destroyed together with their foundations. Some well built wooden buildings and bridges seriously damaged. Dams, dykes and embankments seriously damaged. Railway lines slightly bent. Cement and asphalt roads and pavements badly cracked or thrown into waves. Large landslides on river banks and steep coasts. Sand and mud on beaches and flat land moved horizontally. Large and spectacular sand and mud fountains. Water from rivers, lakes and canals thrown up on banks.

MM XI Wooden frame structures destroyed. Great damage to railway lines and underground pipes.

MM XII Damage virtually total. Practically all works of construction destroyed or greatly damaged. Large rock masses displaced. Lines of sight and level distorted. Visible wave-motion of the ground surface reported. Objects thrown upwards into the air.