

# **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

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 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

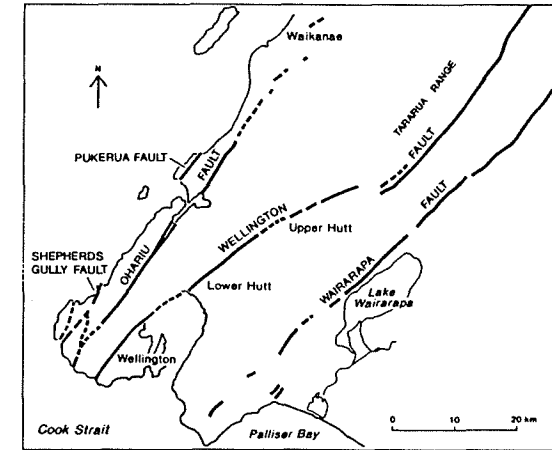


Figure 2: Active faults in the western part of the Wellington Region. (After Van Dissen, 1991).

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.

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

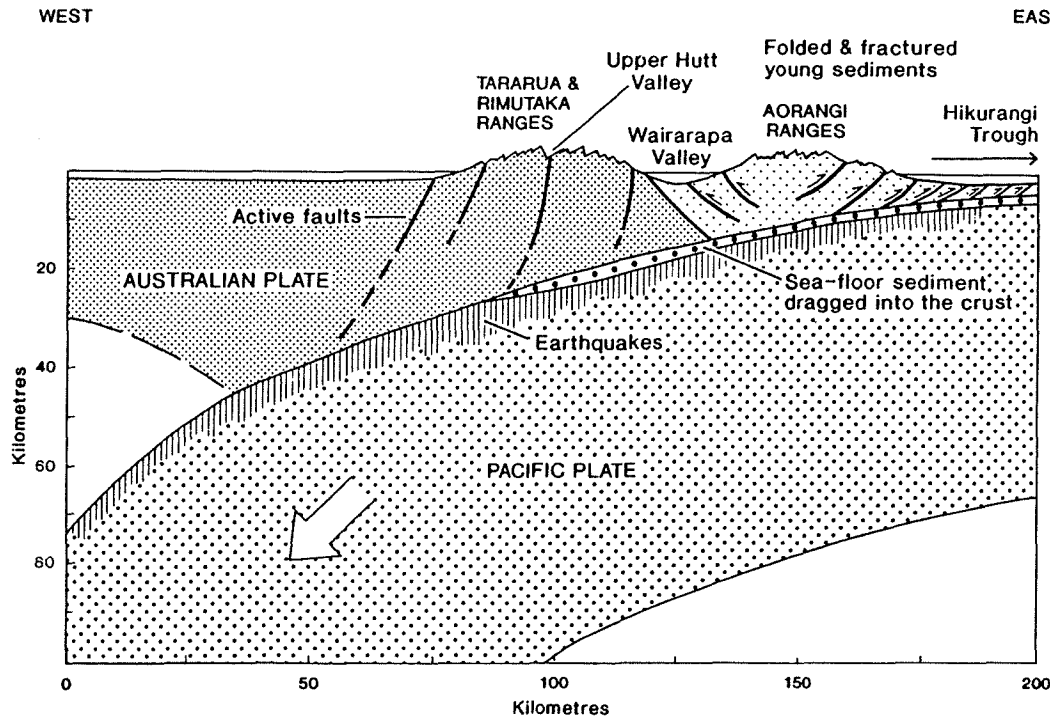


Figure 1: Source of earthquakes at plate boundary and along active faults. (After Stevens, 1991).

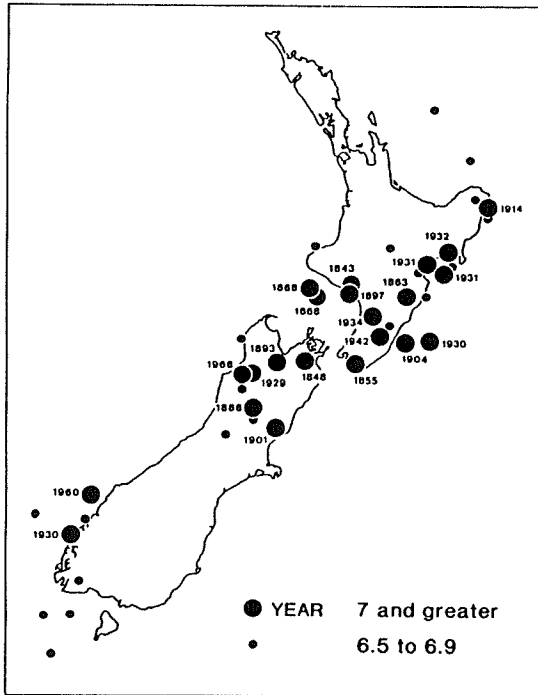


Figure 3: Epicentres of shallow earthquakes of magnitude 6.5 and greater since 1840. (After Van Dissen, 1991).

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:

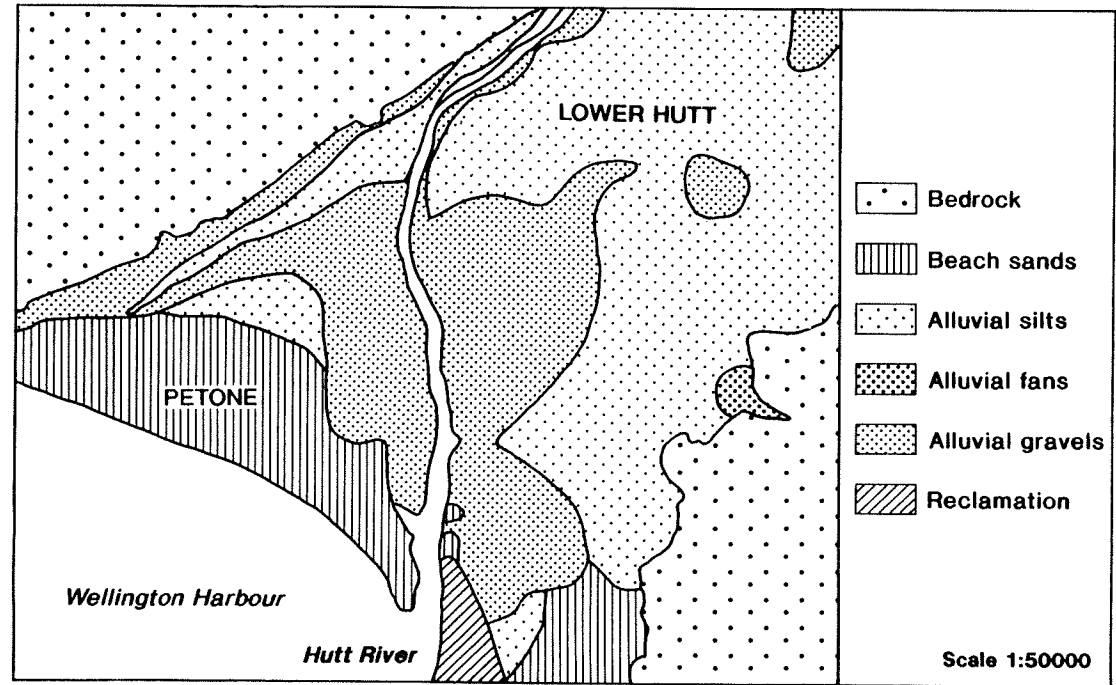


Figure 4: Surface geology deposits in the Petone-Lower Hutt area. (After Read *et al*, 1991).

- \* 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.

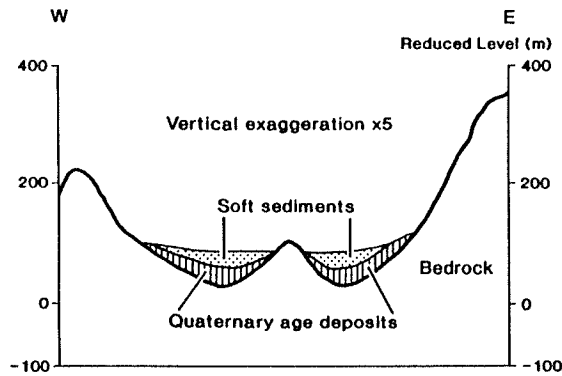


Figure 5: Geological cross section through the Wainuiomata area. (After Read *et al*, 1991).

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.

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.

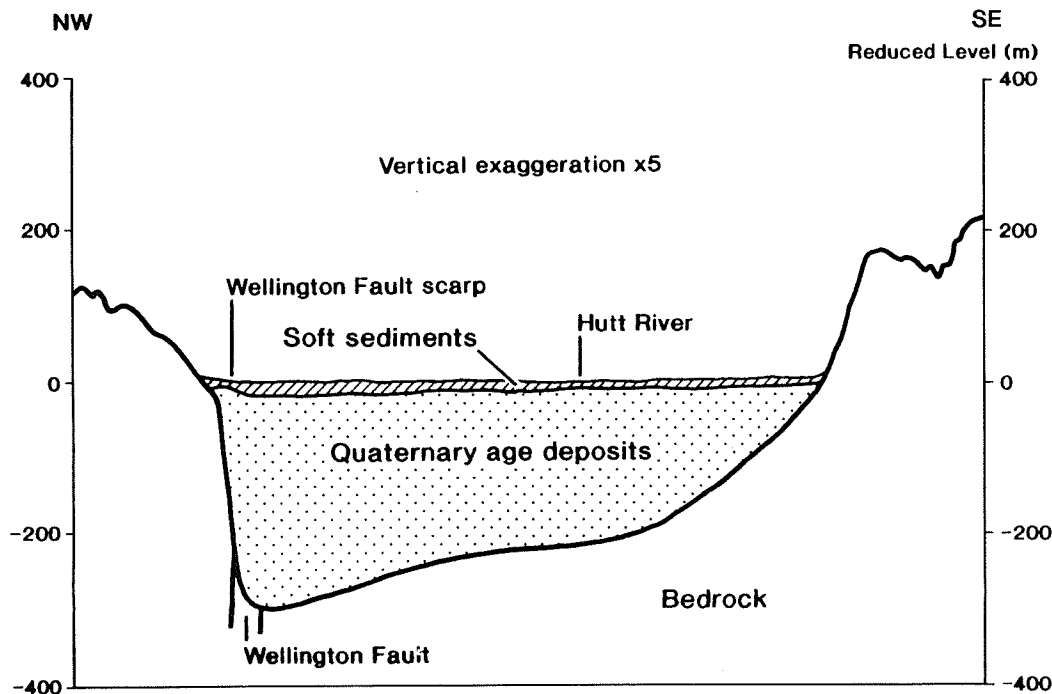


Figure 6: Geological cross section through the Lower Hutt Valley area. (After Read *et al*, 1991).

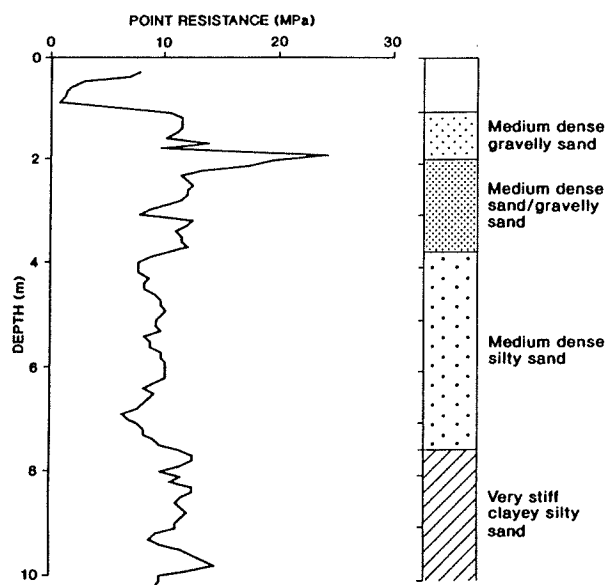


Figure 7: Cone penetrometer test results at Bishop Park, Eastbourne. (After Stephenson and Barker, 1991).

### 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
<b>LOWER HUTT VALLEY</b>				
<i>Soft sediments (to 27 m depth in lower valley)</i>				
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
<i>Coarse-grained alluvial sediments</i>				
Compact sandy gravels (alluvial)	30 - >60		Not tested	Not tested
Silty gravelly sands (fan alluvium)	15 - 30	>20	Not tested	Not tested
<b>WAINUIOMATA</b>				
<i>Soft sediments</i>				
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
<i>Coarse ground alluvial sediments</i>				
Compact sandy gravels	30 - >60			
<b>EASTBOURNE</b>				
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	<0.3 generally between 0.1-0.2	>3x	10-20x
	Wainuiomata (shallow)			
	Wainuiomata (deep)	<0.2 generally around 0.05-0.1		
	Lower Hutt			

SCENARIO 2			
Zone	MM Intensity	Peak ground acceleration (g)	Duration
1	near fault	0.5-0.8	15-40 sec
	Wainuiomata	0.3-0.6	
2	near fault	0.5-0.8	1-2x
	Wainuiomata	0.3-0.6	
3-4	IX-X	0.5-0.8	1-2x
5	near fault	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	<b>"Greywacke"/Argillite Bedrock</b> : Little ground damage. Small (< 100 m <sup>3</sup> ) local failures on steep slopes and unsupported cut batters. Small local failures on cuts in weathered gravels.
2	<b>Alluvial Deposits</b> : Little or no significant damage likely. Small local failures on river banks possible.
3-4	<b>Thicker Alluvial Deposits</b> : 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	<b>Soft Sediments</b> : 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	<b>"Greywacke" Bedrock</b> : Small failures of bedrock and surficial deposits. Widespread on steep slopes and on steep unsupported cuts (>2 m high).
2	<b>Alluvial Deposits</b> : 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	<b>Soft Sediments</b> : 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 zones 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).

Stephenson WR and Barker P R (1991). Wellington Regional Council natural disaster reduction plan - seismic hazard: Report on cone penetrometer and seismic cone penetrometer probing in Wainuiomata, Eastern Harbour Bays, Stokes Valley, Kura Park (Titahi Bay) and Whitby. DSIR Land Resources Contract Report No. 91/21 (prepared for the 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 (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 I** 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.