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Whakatane Microzoning Study
Volume 1 - Text and Figures

Confidential

by R Beetham, G Dellow, J Cousins, V Mouslopoulou,
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& P Barker

Client Report
2004/18
April 2004

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Prepared for

Environment Bay of Plenty

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June 2004

Gracefield Research Centre, 69 Gracefield Road, PO Box 30368, Lower Hutt, New Zealand, Telephone: +64-4-5701444, Facsimile: +64-4-5704600
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EXECUTIVE SUMMARY

The aim of this report is to present the results of a detailed microzonation study of the Whakatane urban area. The study has been carried out under contract to Environment Bay of Plenty, but has been supported by much research work carried out under other programs, particularly those funded by the Foundation for Research Science and Technology. Our study has involved the review of available data and the collection of considerable new data on the geology, the faulting history and the earthquake response properties of soils in the urban area. The report is in two volumes: Volume 1 Text & Figures, and Volume 2 Appendices. Most of the detailed new data is presented in Volume 2, with summary results, synthesis and discussion in Volume 1. A summary of the main findings from both volumes of the study follows.

The geology of Whakatane

- A detailed geological map of the Whakatane urban area has been prepared using both the existing and new data (Figure 2.4).
- With its location at a river mouth, the town of Whakatane is situated mainly on a river plain at the foot of an old sea cliff. The river plain consists of geologically recent, dense beach sands at shallow depth that are covered by weak, loose river and flood plain deposits. The alluvial deposits are several metres thick and tend to increase gradually in thickness away from the old cliff. In places the river plain surface is covered with slightly elevated, former sand dunes.
- The steep, old sea cliffs are formed in a hard, indurated, geologically ancient, strong but closely jointed basement rock mass known as greywacke.
- Much younger weak rocks, also deposited in a marine environment and known as the Ohope Beds, rest unconformably on a planar greywacke surface near the top of the cliffs. The 400,000 to 500,000 year old Ohope beds are draped with layers of volcanic ash (tephras) erupted over the last few tens of thousand years from various volcanic sources in the Taupo Volcanic Zone (TVZ). The Ohope Beds and tephra deposits on top of the greywacke have been eroded to form moderate to steep sided hills and valleys

The Whakatane Fault

- The Whakatane Fault is active. It off-sets high river terrace remnants at Pukehoko, 6 km to the south of Whakatane. North of Pukehoko and through the Whakatane urban area the plains of the valley floor are very recent and it is apparent that a past fault scarp has been eroded away by the Whakatane River. However, marine seismic profiling by NIWA off-shore in the Bay of Plenty has located measurable vertical offsets on many submarine faults (Appendix 1). One of these faults, the Keepa Fault, is considered to be the offshore extension of the Whakatane Fault because of its position and an offset that demonstrates recent activity. By linking the Keepa Fault with the Pukehoko fault trace, an approximate location for the fault through Whakatane town can been drawn. It is emphasised that, as fault traces generally have curvature and occasional small offset steps, the location for the fault through the urban area is an estimate. The true location of the fault could be within a distance range of 1 km or so through the northern part of the town.

- An earthquake caused by rupture of the Whakatane Fault would be likely to produce a predominantly normal fault scarp some 2 to 3m high through the urban area. For long-term planning it is therefore important to better locate the fault so that the fault scarp rupture hazard can be avoided. As well, geological evidence indicates that rupture of the fault through Whakatane is most likely to result in a relative down-throw of 2 to 3m of the ground surface on the western side of the fault. The down-thrown part of Whakatane and the plains beyond would be close to sea level, would be far more susceptible to flooding from the river and would be difficult to drain. A similar sized down-throw of ~2m or less on the north-western side of the Edgecumbe Fault resulted from the 1987 earthquake.
- An effective method for locating the fault would be by measuring gravity profiles across the urban area. Using the average vertical movement rate of 2mm/year on the fault with the 500,000 year age for the base of the Ohope Beds, it is apparent that the greywacke surface could be offset vertically by as much as 1 km by the fault. This, or a somewhat smaller degree of basement rock offset, provides a density contrast across the fault that would allow its ready location using a detailed gravity survey. More accurate locations could possibly be made using shallow seismic refraction and reflection profiling, perhaps in the town, along the beach between Thornton and the Whakatane River mouth, or in shallow water offshore. Drilling to confirm its position may be an option once the general location of the fault was better known.

Earthquakes affecting Whakatane

There are three scenario earthquakes that best describe microzoning effects in Whakatane.

- (**1**) The least, almost undamaging event, is a large earthquake 20 to 50 km or more away that generates MM6 intensity shaking (or less) in Whakatane. This type of earthquake occurs approximately every 10 years. It will be strongly felt in Whakatane as the weak near surface soils amplify the shaking, possibly increasing the felt intensity from MM6 to MM7, but damage should be minor and restricted to interior damage such as a few items falling from shelves. There will not be any significant liquefaction or ground damage effects at this intensity.
- (**2**) Lightly to moderately damaging for Whakatane is an earthquake nearby in the TVZ or on one of the closest Shear Belt faults (the Waiohau or Waimana faults – Figure 2.2). This earthquake may cause strong MM7 to MM8 intensity shaking in Whakatane, similar to the 1987 Edgecumbe Earthquake. It would cause minor ground, structural and interior damage and perhaps a few casualties. This type of earthquake is likely to occur approximately every 100 years.
- (**3**) The most damaging for Whakatane would be an earthquake on the Whakatane Fault through the town. This earthquake would cause very strong MM9 and 10 intensity shaking in Whakatane, would cause widespread liquefaction and ground damage in the town, rockfalls and landslides on the cliffs and road cuts, a 2 to 3 m high fault scarp through the urban area with 2 to 3 m of ground surface down-throw on the western side of the fault scarp. There would be extensive building damage and some casualties. Although well built houses should be structurally undamaged, the inside contents will be heavily damaged, similar to houses in Edgecumbe township after the 1987 earthquake. There would be extensive damage to buried service networks, especially brittle pipes. Roads and

bridges into Whakatane would be damaged and probably impassable, possibly for some time. This is a rare earthquake that may occur approximately every 1,600 years. The last such event is thought to have occurred at least several hundred years ago, but a more exact date has not yet been determined.

Sub-surface investigations and material properties in Whakatane

- Extensive subsurface investigations were carried out to determine the soil conditions in the Whakatane urban area, so that their response to strong earthquake shaking could be assessed.
- Cone Penetrometer (CPT) and Seismic Cone Penetrometer (SCPT) Testing in Whakatane shows that the moderately dense to dense former beach sands are less than 10 metres beneath the surface (shallower closer to the old cliffs). Their shear wave velocity is ~200m/s and cone resistance (qc) generally >20MPa.
- The dense beach sands are well within reach of piles. Piling therefore appears to be a good foundation option for support of heavier buildings and to help prevent liquefaction related ground damage to houses in susceptible areas.
- The overlying flood plain and sand dune deposits are weak/loose, poorly consolidated sands and silts with a low shear wave velocity around ~100m/s (range 66 to 148m/s) and cone resistance <10MPa. Where the ground water level is high and these upper materials are saturated they have high liquefaction potential and will begin to liquefy at MM7 intensity shaking. However, in the areas of former sand dunes, such as at the Hospital, the water table is recorded as being low and the liquefaction potential is therefore lower (see Figure 4.4).
- A survey of 53 sites in Whakatane with a sensitive seismograph has allowed the derivation of the natural period of the ground throughout the town using Nakamura analysis (Figure 4.1).
- The sub-surface investigation have enabled us to classify the ground in Whakatane according to the new NZ building code into “rock”, shallow or stiff soil, and deep or soft soil categories (Figure 4.3) for estimation of spectral accelerations for different period structures. Probabilistic seismic hazard spectra are provided for 475 and 2,500 year return periods.

Ground damage liquefaction and amplification in Whakatane

- The ground damage due to liquefaction includes sand boils, lateral spreading and the plastic yielding of soil to cause permanent ground deformations It can begin to occur at MM7 shaking intensity and increases in severity with increasing intensity above MM7, to reach a maximum at MM10 (see Appendix 4). Such ground damage is unlikely to cause major damage to well built houses or to larger, well built buildings founded on piles, but could cause extensive damage to buried networks, such as brittle pipe systems. Water-front areas and river and canal banks can be severely damaged by lateral spreading and slumping.
- The natural period of amplifying soil sites in Whakatane has been calculated using the Nakamura method. The method analyses seismograph records of naturally occurring ground vibrations. This work shows that the natural period of the ground decreases away

from the cliffs (Figure 4.1). Within approximately 500m of the old cliffs the natural period of the ground is less than 0.6s. There is then a gradual decrease in period to the area SE of the Landing Bridge that has a natural period >3s (see Figure 4.1).

- To avoid resonant amplification effects, the natural period of built structures should not be close to the natural period of the ground. The natural period of a single storey house is about 0.1s and a 3 storey building about 0.3 s.

Earthquake triggered landslides in Whakatane

- The earthquake triggered landslide hazard in Whakatane is considered to be generally moderate along the old, steep sea cliffs behind the town and at their toe which is in the landslide run-out zone, is low in the hill suburbs and non-existent on the plains (see Figure 4.5). However, the landslide hazard increases along the old cliffs and on the hills during the much less frequent Whakatane Fault earthquake caused by fault rupture through the town. This earthquake would cause significant, damaging landsliding during its very strong, MM9 to 10 intensity shaking. By contrast for the other more frequent earthquakes that may cause MM7 to MM8 intensity shaking in Whakatane, the landslide damage is likely to be minor.

Earthquake design spectra for Whakatane

- All known earthquake sources have been used in the NZ probabilistic Seismic hazard model to derive the 475 and 2,500 year recurrence interval earthquake design spectra for Whakatane (Figures 5.1 & 5.2). The 475 year recurrence interval spectra have a 10% probability of occurrence in 50 years and are commonly used for the design of non-critical structures, while the 2,500 year spectra are used for the design of critical structures such as bridges, hospitals and schools.
- The design spectra are derived for each of the four (strong rock, weak rock, shallow or stiff soil, and deep or soft soil) rock and soil classes determined to be present in Whakatane (Figure 4.3).

Costs and casualties due to earthquakes affecting Whakatane

- A methodology based on damage and casualties caused by past earthquakes has been developed by GNS to estimate the losses from future earthquakes. With a good knowledge of the national building stock and population, the methodology allows the losses for different sized earthquakes in different parts of the country to be estimated. Tables 6.3 and 6.4 respectively show the estimated building damage costs and casualties for the region and the urban centres for both a magnitude 7.4 earthquake on the Whakatane Fault and for a magnitude 6.3 earthquake on the Edgecumbe Fault. The losses are estimated for both a day and a night-time earthquake event.

1.0 INTRODUCTION

The objective of this report is to present the findings of a detailed microzonation study of the Whakatane urban area. The study has been carried out under contract to Environment Bay of Plenty. However, it has built on and been supported by much research work carried out under other programs at GNS and NIWA, particularly those funded by the Foundation for Research Science and Technology. Our study has involved the review of available data and the collection of considerable new data on the geology, the faulting and the earthquake response properties of soils in the urban area. The report is in two volumes: Volume 1 Text & Figures, and Volume 2 Appendices. Most of the detailed new data is presented in Volume 2, with summary results, synthesis and discussion in Volume 1.

1.1 Invitation to tender

In January 2003 Environment Bay of Plenty called for registrations of interest from organisations capable of undertaking a geological mapping and micro-seismic zoning study of the Whakatane Urban Area. GNS responded by submitting a proposal.

Our proposal follows the details outlined in the Call for Registration of Interest, and was prepared after discussions with Mr Russ Martin of Environment Bay of Plenty. The study concentrates on the Whakatane Urban area.

1.2 Project overview

The town of Whakatane is the largest urban area located near the junction of two major fault belts, the eastern margin of the Taupo Volcanic Zone and the North Island Shear Belt (Figure 1 Appendix 1). Environment Bay of Plenty has determined that the assets and infrastructure within the Whakatane urban area justify a detailed assessment of the seismic risk, specifically for risk mitigation by way of long-term land-use planning purposes, as well as consideration of lifeline vulnerabilities.

Having recognised the susceptibility of the Whakatane urban area to earthquake hazards, Environment Bay of Plenty is taking pro-active steps to analyse the hazard and assess the risk.

As defined in the Call for Registration of Interest, the major outcomes of the study are:

1. A detailed geological map of the Whakatane urban area including the location of the Whakatane Fault, determined as accurately as possible;
2. Earthquake hazard maps showing zones of relative shaking hazard and likely ground damage impacts; and
3. A report clearly explaining the maps and presenting the results so that the information is easily applied to land-use planning for risk mitigation.

1.3 Phase 1 Geological maps

Objective To produce a detailed geological map at a scale of 1:5000 of the Whakatane urban area in a GIS. The base map will use the LIDAR contour data supplied by Environment Bay of Plenty as a base map (except for a small area outside LIDAR boundaries where NZMS 260, 20 metre contour data is the default data unless better data is made available from elsewhere).

Tasks Compile and collate geological and geotechnical information from available sources. Potential data sources include:

- Published work (e.g. Healy et al, 1964; Berrill et al 2001);
- Information held in GNS files and other unpublished work that may be available (e.g. University theses);
- Subsurface information held by Whakatane District Council and Environment Bay of Plenty (extracting geological and geotechnical information); and
- Geophysical information held by GNS.

Undertake an aerial photograph interpretation of the area to help delineate geological units.

Field mapping to check data compiled and to gather information on areas where none currently exists.

Locate the position of the Whakatane Fault as accurately as possible.

Produce a preliminary geological map in a GIS of the Whakatane urban area at a scale of 1:5000.

1.4 Phase 2 Geotechnical characterisation of the ground

Objective To determine the response of the mapped geological units to strong and weak earthquakes with respect to liquefaction, landslides and amplified ground shaking.

Tasks If required, undertake field investigations using the Nakamura method and the techniques of John Louie to determine the relevant geotechnical parameters of the mapped geological units (e.g. V_s30 - shear wave velocity).

From historical reports, determine the behaviour of the geological units during historical earthquakes.

Geotechnical characterisation of the geological units, in terms of the Loadings Code Standards, so that a seismic hazard analysis can be undertaken.

(The need for field investigations with be discussed with Environment Bay of Plenty)

1.5 Phase 3 Ground shaking, liquefaction and landslide hazard maps

Objective To produce a clear and concise report and maps characterising the ground shaking behaviour of the geological units in a form that is readily accessible to land-use planners and is consistent with New Zealand code standards.

Tasks Using the geological map developed in phase 1 and the geotechnical characterisation of the units determined in phase 2 (including relevant soil parameters such as V_s30) a suite of hazard maps will be produced. This will include a ground shaking hazard map (based on the Proposed NZ/Aust Loadings Code), a liquefaction hazard map and a landslide hazard map.

For the ground shaking hazard map, earthquake spectra will be provided for each of the ground classes mapped.

Return periods for various shaking intensities and spectral accelerations (expressed as probabilities) will be provided.

From these damage ratios for building and utility stock can be produced.

The final step in this approach is to describe the likely response of various classes of building and utilities in each of the ground shaking hazard zones. This will allow land-use planners to quickly assess the appropriateness of locating buildings and services of different types and uses in each of the zones and to make recommendations as to the appropriate style of development.

This report prepared by GNS outlines the work carried out, the methodologies used and the results achieved.

1.6 Discussion of terminology used

1.6.1 Microzonation phenomena

Microzonation is the term used to describe how local ground effects modify the seismic shaking that is experienced at a specific site. Various phenomena can be involved. Of most relevance to seismic risk studies are the amplification and de-amplification of shaking by soft or weak soils, ground damage effects due to liquefaction, landsliding, and topographic enhancement of strong shaking on steep slopes and ridges. The report considers all these effects in the Whakatane urban area.

1.6.2 Amplification

Amplification of seismic shaking by soft soil is a controversial subject. While certain types of soft and weak soils can greatly amplify low levels of input rock motion while the soil remains elastic, once the soil is excited beyond its elastic range (Modified Mercalli (MM) 7 intensity and above – see Appendix D for MM Intensity descriptions) the soft soils can isolate surface structures from the strong, high frequency shaking.

Amplification is most obvious when the input rock motions are relatively weak and caused by large, distant earthquakes. An extreme example occurred in Mexico City in 1985. The earthquake causing the damage was a magnitude 8.1 event located near the Pacific coast of Mexico about 400 km away from the city. On firm ground adjacent to the city the shaking intensity was quite weak, about MM5, but on certain soft, deep soils within the city shaking was strong enough to seriously damage many modern high-rise buildings and kill more than 10,000 people. One reason for this was a double resonance effect. Areas of soft soils that had resonant periods of about 2 seconds were preferentially set in motion by the incoming seismic waves, and buildings that had the same resonant frequency, typically being those 8-16 stories high, swayed particularly strongly. Many collapsed. Nearby buildings of weak stone masonry construction were undamaged because their natural periods did not match the resonant period of the soft soils (McManus and Berrill 2001).

A second example occurred in San Francisco during the 1989 Loma Prieta earthquake. Downtown San Francisco was nearly 100 km from the epicentre of the magnitude 7.1 earthquake. On firm soils and rocky areas of the city the prevailing intensity was MM6, increasing to MM7 on some adjacent softer soils and to MM9 in some small pockets of very soft soils (Benuska 1990). However liquefaction effects also contributed to the damage associated with the very soft soils.

In both Mexico City and San Francisco the soft soils have repeatedly shown the same amplification effects, e.g. in Mexico City in 1957, 1979 and 1985, and in San Francisco in 1906 (Borcherdt and Gibbs 1976) and 1989.

What happens at these locations when the input motions are very strong is not at all clear, however. In 1931 when Napier was subjected to MM10 shaking from the nearby, magnitude 7.8 earthquake, for example, shaking damage to houses increased with the strength of the subsoil. Houses on ground classified as rock were, on average, more badly damaged by ground shaking than houses on ground classified as firm soils and gravels, which in turn were more badly damaged than most houses on ground classified as soft soil (Dowrick et al 1995). In this case it is likely that the rock and strong soils transmitted more of the high frequency ground motions with a short period in the range of 0.1 seconds that is similar to the resonant period of houses and consequently most damaging to them. (Note that houses on soft soil that suffered lateral spreading, about 10% of all houses on soft soil, were the most badly damaged of all and are excluded from the above discussion.).

A second example of the “isolation” effect of soft soil was noted in Los Angeles after the magnitude 6.4 Northridge earthquake of 1994. Over a considerable area there was an anti-correlation between house damage and pipe damage, i.e. where houses were highly damaged underground pipes were not and vice versa. It seemed that where there were large strains in the soil (but excluding regions of differential settlement and lateral spreading) the soil absorbed enough seismic energy to significantly protect the houses on it, while extensively damaging the buried pipe networks (Trifunac and Todorovska 1997 & 1998).

Amplification of weak seismic shaking by soft soils has been seen many times in recordings made by arrays of seismological instruments in Wellington, Lower Hutt and Porirua (Sritharan and McVerry 1992 & Taber and Smith 1992). Conversely, data from around the world shows that peak ground accelerations and short-period vibrations appear to be attenuated on soft soils for accelerations above about 0.4g, i.e. for intensities greater than about MM8 to MM9.

To summarise, amplification of seismic shaking intensity in soft or weak soils is expected to occur according to the following:

- for all periods at low levels of excitation (< MM8) and
- for long periods (> 0.6 seconds) only at strong levels of excitation (> MM8).

1.6.3 Topographic enhancement of shaking

Amplification of shaking can also occur at the crests of ridges and hills, the effect being somewhat analogous to the increase of height in water waves approaching the edge of a beach. Increased damage to structures can occur as a result. We have neither maps of the relative level of risk from topographic amplification, nor firm data that would enable us to quantify the additional damage that would result from topographic enhancement of shaking. For the Whakatane Urban area, any topographic enhancement is expected to be restricted to the crest area of the old sea cliffs.

1.6.4 Liquefaction

Liquefaction is the term used to describe the loss of bearing strength experienced when uniformly graded, saturated, sands and silts are subjected to dynamic shaking. Its effects can range from harmless sand boils to serious ground damage such as subsidence, lateral spreading and loss of bearing strength. At intensities of MM6 to MM7 the effects of liquefaction are nearly always small and rarely cause significant damage to buildings and equipment. At higher intensities, MM8 and above, ground damage (settlement, spreading or displacement) often occurs and can result in substantial damage to buildings. In New Zealand liquefaction in natural ground tends to occur in swampy and esturine areas where sediments have accumulated in a quiet, low energy water environment such as the lagoons and swamps near river mouths or in port areas. Parts of Wanganui, Whakatane and the Rangitaiki plains, Port Wellington, Port Nelson and Kiapoi are examples of areas with high liquefaction potential.

Not all assets are equally at risk from liquefaction. Recent experience shows that well-founded buildings can withstand the effects of liquefaction. During the Kobe (Japan) earthquake of 1995 for example high-rise buildings on piles were almost completely undamaged by the severe liquefaction that affected several tens of square kilometres of ground and paralysed one of the world's largest container ports. Of course the services connections to the buildings were severed when the ground around the buildings settled by about 0.5m, but the buildings themselves suffered only minor shaking damage (Park et al 1995). Some of the smaller buildings showed various amounts of tilting and settlement, but most did not.

Structures that are either buried in the ground, or are on the surface but are not mechanically stronger than the ground beneath them, are much more susceptible to liquefaction-related damage than are buildings (Rojahn et al 1985). Included in this category are buried pipelines, buried tanks, stopbanks, earthen dams and other earthworks like drains.

Potentially liquefiable soil types occur under most of the Whakatane urban area located between the foot of the cliffs and the river. However, the 1987 Edgecumbe earthquake which caused MM7 shaking in much of the Whakatane urban area, shows that liquefaction damage can be expected to be minor unless the shaking intensity is greater than MM7. Reports of liquefaction in the Whakatane urban area after the Edgecumbe earthquake are well documented in a thesis study by Christensen (1995).

1.6.5 Earthquake-induced landslides

Strong shaking during large earthquakes is a major cause of landslides in New Zealand. Factors that are important in determining the stability of slopes include slope angle, slope height, Man-made slope modifications, the underlying rocks and soils (geology), existing landslides, and groundwater content (Hancox et al 2002). Properties below and above areas of high landslide susceptibility are also at risk from burial and undermining respectively, should landsliding occur.

Slope instability in the Whakatane urban area is confined mainly to the old sea cliffs behind the town and part of the hills between Whakatane and Ohope. Small-scale failures occur along the river in some areas, although these can be associated with liquefaction.

1.7 Limitations of the study

Our study has approximations and limitations that are inherent in most earth science assessments that attempt to model complex ground conditions and processes. As well the study is reliant on available information and on scientific and engineering judgement. We are dependant on descriptions and interpretations of past events and subsurface ground conditions made by others. The estimated probabilities of various events have a relatively high degree of uncertainty because of the (natural) processes involved. However, we have tested and validated our assumptions where we can and we are satisfied that we are presenting good indicative and useable results. The report has been prepared on the best information available to us using our best endeavours.

1.8 Acknowledgements

We wish to thank both Environment Bay of Plenty and Whakatane District Council for their help and provision of subsurface data, maps, aerial photograph and contour data. Their timely responses to requests for information are appreciated.

Although the study has been carried out under contract to Environment Bay of Plenty, it builds on and is supported by the results of much research work carried out under other programs by our colleagues in GNS, particularly the programs funded by EQC and the Foundation for Research Science and Technology (FRST). NIWA has provided information on offshore faulting in the Bay of Plenty (Volume 2, Appendix 1), and Vasso Mouslopoulou has provided information on the onshore faulting from her current PhD studies.

At GNS Richard Jongens, Biljana Lukovic and Philip Carthew have provided assistance with GIS and the preparation of figures, Graham Hancox and Pilar Villamor have reviewed the text and figures and Penny Murray has formatted the report.

The considered and helpful approach of Mr Russ Martin at EBoP has facilitated the completion of this complex report.

2.0 GEOLOGY

An essential component of a microzoning assessment is consideration of the recent geological history of the area being studied. The geological environment, including the types of rocks and soils, the depositional history of sediments, the location of rivers, the sea and activity of faults, volcanoes, and uplift or down warping can all influence the response of an area to earthquakes. By considering these geo-environmental factors in conjunction with existing and new ground testing data, this report assesses the likely response of the soils and rock within the Whakatane urban area to earthquake shaking.

2.1 A brief geological history of the Whakatane area

Whakatane is located in an active geological environment. Off the East Coast the Pacific Plate is being subducted beneath the North Island land mass from the east along the Hikurangi Trench at a rate of 47mm per year, uplifting the region including the Whakatane area (Figure 2.1). As well Whakatane is located on the south-eastern edge of the Taupo Volcanic Zone (TVZ), a zone of active back-arc rifting (extensional faulting) and volcanism, the source of the largest historical volcanic eruption at Tarawera in 1886 and the recent most damaging earthquake near Edgecumbe in 1987. In addition Whakatane is directly situated on the active Whakatane Fault near the centre of the North Island Shear Belt faults, the Waiohau, Whakatane, Waimana, and Waikaremoana faults (Kear 2003) and is close to where these faults merge with the TVZ (Figure 2.2). Mt Edgecumbe (Putauaki), Whale Island (Motuhora) and White Island (Whakaari) volcanoes are distinct reminders of the volcanic activity of the TVZ near Whakatane (Figure A1). However, the less distinctive Okataina Volcanic Centre,

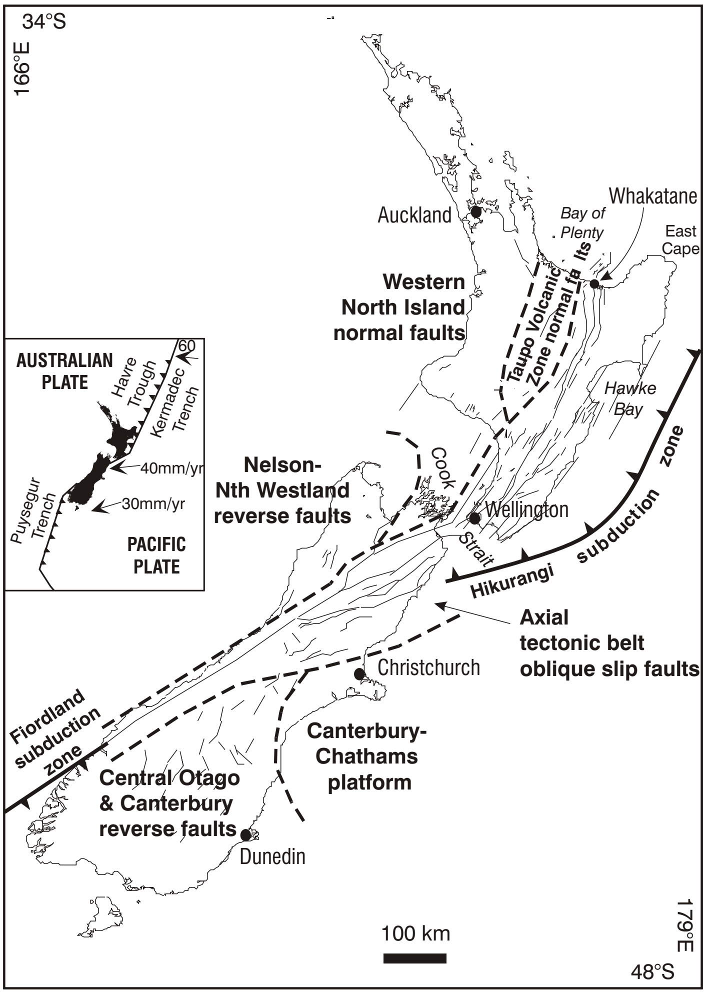


Figure 2.1: Tectonic setting of New Zealand.

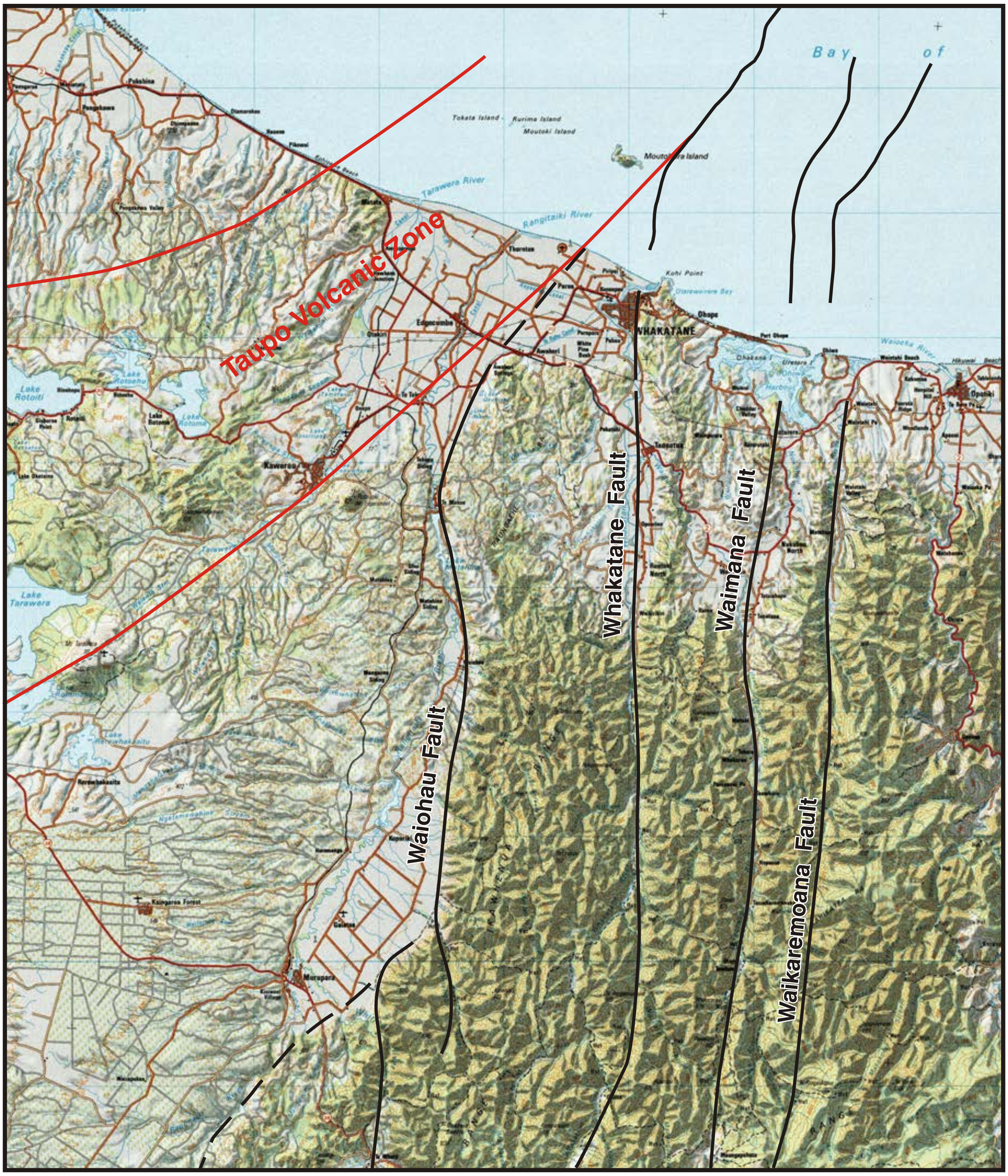


Figure 2.2: The main tectonic features of the study area.

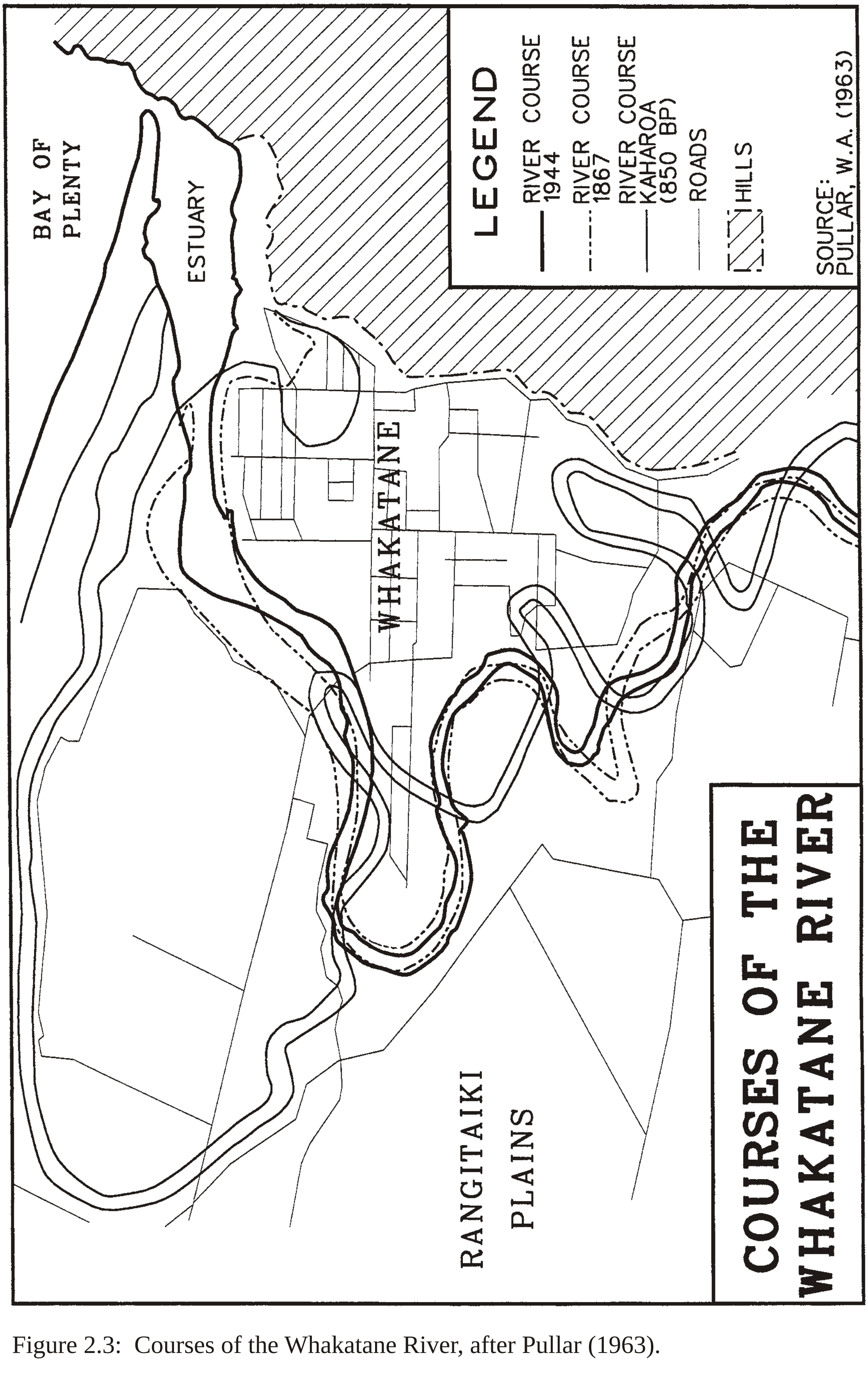


Figure 2.3: Courses of the Whakatane River, after Pullar (1963).

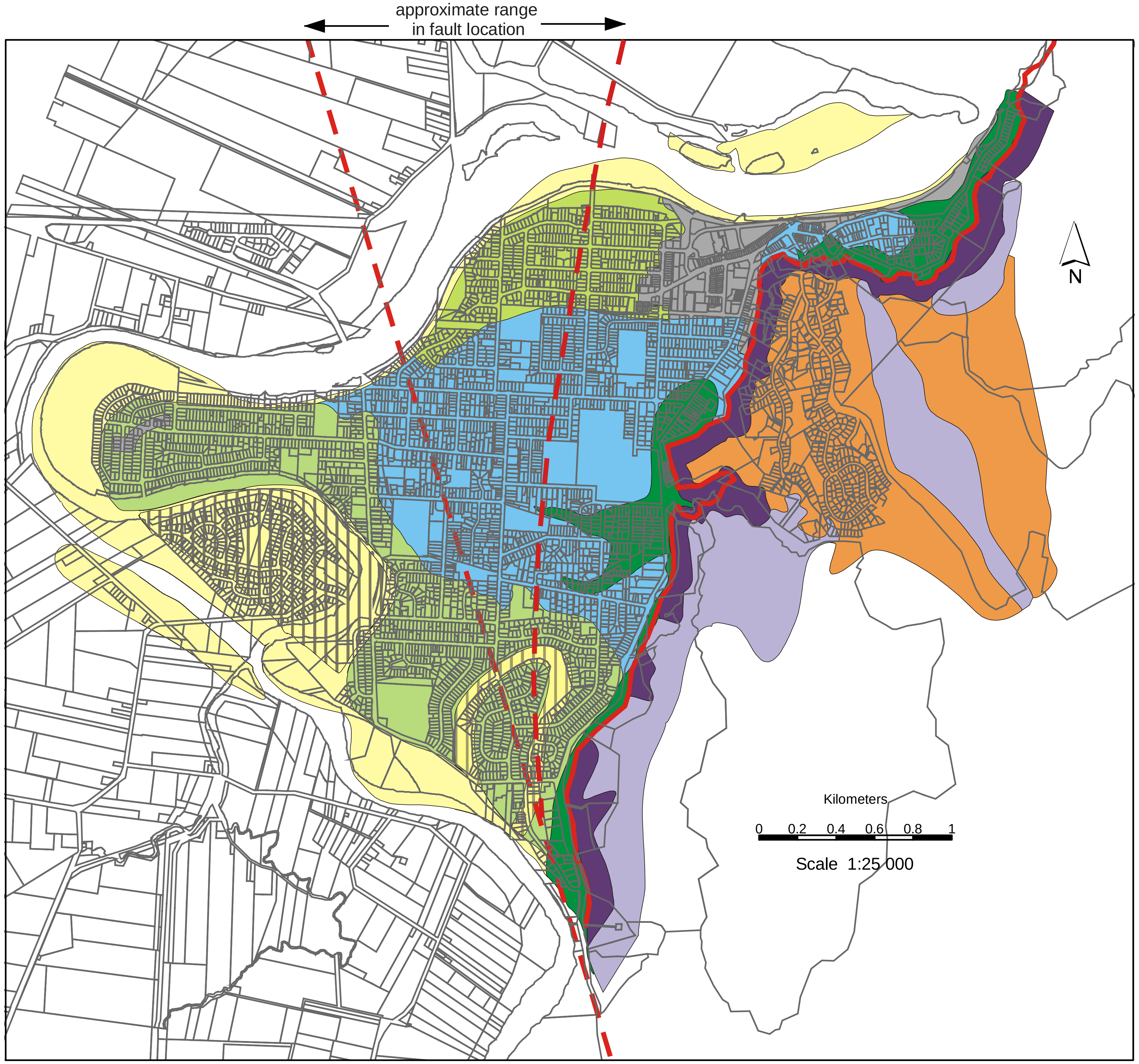


FIGURE:	Figure 2.4
PROJECT:	Whakatane Microzoning
TITLE:	Surface geological map of the Whakatane Urban area.
DATE:	January 2004
DRAFTED BY:	J. Hoverd
PROJECT NO.:	430W1029
CR:	
EXPLANATION:	Surface Geology based on Pullar (1978). Base Map: Whakatane District cadastral data.
LEGEND	🟧 Tephras 🟪 Weathered Greywacke 🟪 Unweathered Greywacke 🟩 Colluvium 🟦 Dunes ⬛ Fill 🟩 Protected overbank silts 🟨 Active overbank silts ▥ Protected meander troughs — Base of former coastal cliff - - - Estimated location of fault

which includes Mt Tarawera, has been the source of the largest eruptions that have effected the region. For example the Okataina Volcanic Centre was the source of the Matahina Ignimbrite some 280,000 years ago, an eruption that produced some 120 cubic kilometres volume of molten ignimbrite rock which reached as far as Whakatane and the Waimana River (Kear 2003). The most recent volcanic eruptions to significantly effect Whakatane urban area were the Tarawera eruption 118 years ago (depositing 3 – 8cm of scoria), Kaharoa pumice (8 – 15cm thick tephra) 770 years ago, Taupo pumice (10 – 15cm thick) 1,800 years ago and Mapara, Whakaipa & Waimahia lapilli (~5cm thick) 2,200 – 3,300 years ago.

The basement rock at Whakatane is thinly interbedded, strong and hard greywacke sandstone and argillite about 140 million years old that forms the cliffs behind the urban centre. Much younger gravel, sandstone and siltstone Ohope Formation sedimentary rocks about 500,000 years old that contain fossils similar to present day shells, and pumice, sit on a planar erosional surface on the greywacke and form the upper part of the cliffs between Whakatane and Ohope. On top of the Ohope Formation beds are up to several metres total thickness of tephra (volcanic ash) layers.

Most of the Whakatane urban area below the old sea cliffs is located on the flood plain of the Whakatane River, an area of geologically recent soils. This flood plain and the Rangitaiki plains have together been gradually built up by accumulating river sediments, beach and sand dune deposits over the last 5,000 years, a natural process that is continuing today. The part of the urban area that includes the housing on top of the cliffs off Hill Crest and Gorge Roads, consists of a thickness of Ohope Formation beds and tephras overlying greywacke basement rock. This part of the urban area is classified here as a (weak) rock and shallow soils areas Section 4).

About 20,000 years ago, at the end of the last glacial period that affected the world, the sea level was some 120m lower than present because of the large volume of water accumulated in ice sheets. As the worlds’ climate warmed the ice sheets melted and the sea level gradually rose to reach a level close to present day level some 7 to 10,000 years ago. At this time sea reached inland to carve the old cliffs at Awakeri and to form a beach at Te Teko. Since then accumulating sediments have caused the coastline to retreat about 10 km to its present position, so that the cliffs behind Whakatane are no longer under erosion attack by either the sea or the river.

As the plains have accumulated and the coastline has retreated the Tarawera, Rangitaiki and Whakatane rivers have all changed their courses. The most recent courses of the Whakatane River are shown in Figure 2.3 (Pullar, 1963). A cut off loop of the river now forms Sullivan Lake and in the 1960’s the river was straightened to form the Awatapu Drive cut off loop.

The present day geological map of the Whakatane urban area (Figure 2.4) reflects this history. The old greywacke rock shore platform at the foot of the cliffs behind Whakatane is buried by a combination of scree and debris fans from the cliffs and by beach and river sediments, while on the river flood plain there are river and swamp deposits between old sand dunes. Beneath the ground surface investigations show that the debris fans and sand dunes rest on several metres of loose, interbedded sand and silt river sediments which in turn rest on dense, former sea bed sands. The loose river sediments increase in thickness to reach approximately 10m depth near the river at Trident High School and Awatapu Drive.

3.0 FAULTING

There are many known active faults that can cause strong ground shaking in Whakatane when they rupture. These are the faults of the North Island Shear Belt and the faults within the Taupo Volcanic Zone (Figure 2.2 & Appendix 1, Figure 1). Because of its inferred presence within the urban area, the Whakatane Fault (Figure 2.4) has the greatest potential to cause damage due to surface rupture, the strongest possible MM10 ground shaking and down-warping. Rupture of the Whakatane Fault through the town is expected to produce a 2 to 3m high scarp with down-throw of the ground surface on the western side. The fault scarp is expected to be a sub-vertical break similar to the 2m high Edgecumbe Fault scarp.

Preliminary onshore studies for a PhD by Vasso Mouslopoulou indicate that the interval between ruptures of the Whakatane Fault is 1,140 to 2,230 years (Table 3.1). While the timing of the last rupture has not yet been determined, it is likely to be more than several hundred years, as the scarp has been eroded away in many places and is now preserved offshore and to the south of Whakatane at Pukehoko where it is somewhat degraded.

The location of the Whakatane fault beneath the urban area can be inferred by drawing a line down the Whakatane Valley from its last location seen at Pukehoko. Alternatively, if the fault line is curved to join to the Keepa Fault (Figure Appendix 1, Figure 3) between the two known locations to the north and south, the fault location moves some distance to the east (Figure 2.4). This is quite plausible as a fault trace that curves to the east is a probable consequence where the shear belt faults join into the extensional rifting of the Taupo Volcanic Zone. The difference between these two possible fault locations in the northern part of the urban area is approximately 700m. Movement of the inferred continuation of the Whakatane Fault offshore has been established by NIWA (Appendix 1) as part of their comprehensive offshore study of faulting in the Bay of Plenty using ship-board data acquisition and seismic surveys.

Because of their locations some kilometres distance from Whakatane (Figure 2.2 & Appendix 1, Figure 1), the rupture of other faults within the North Island Shear Belt and the TVZ would produce strong shaking of similar (or smaller) intensity to the 1987 Edgecumbe Earthquake, which caused Modified Mercalli (MM) 7 to 8 intensity shaking in Whakatane (see Appendix 4 for MM Intensity descriptions).

Thus the earthquake scenarios for Whakatane can be divided into two main events:

1. Rupture of the Whakatane Fault approximately every 1,100 to 2,300 years producing surface rupture and very strong MM10 intensity shaking within the urban area. The very

strong shaking, associated ground damage due to liquefaction and landslides, and the downwarping on the western side of the fault scarp, means this is the most severe and damaging earthquake for Whakatane.

2. Rupture of other near-by active faults which have the potential to occur more often (approximately every 30 to 200 years) but which will have about the same strength of shaking in Whakatane as the MM 7 to 8 intensity shaking experienced in the 1987 Edgecumbe Earthquake.

A third case is a large earthquake that occurs on a fault 20 to 50 km or more away, causing shaking in Whakatane of MM6 intensity or less. Such an event is likely to be strongly amplified by the weak soils present under much of Whakatane – compared to sites on rock, but will not be significantly damaging to the town.

3.1 The onshore Whakatane Fault

The Whakatane fault is active and extends from Ruatahuna valley as far as the Bay of Plenty. It is the northward extension of the Mohaka-Wellington Fault and appears to carry both dextral longitudinal and dip slip movements. The closest onshore trace of the Whakatane Fault to Whakatane lies 6 km south of the town at Pukehoko location (Fig. 3.1).

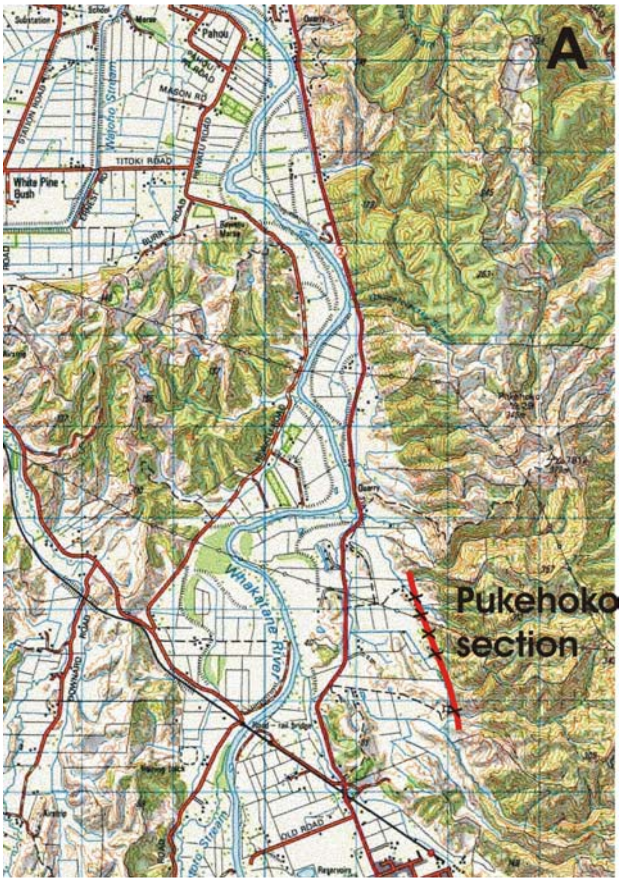


Figure 3.1 Location map showing the Pukehoko section of the Whakatane Fault. This is the closest to Whakatane clear trace of the fault where five offset spurs have been identified and surveyed.

Five offset landforms are recorded along the Pukehoko section of the fault. The displacements have been mapped in detail using Real Time Kinematic-GPS surveying technology. For three of those offsets, micro topographic maps with associated shaded relief maps have been compiled. Topographic profiles of the offset landforms have been constructed parallel to the fault in order to accurately estimate the associated displacements (Figure 3.2).

The existing information regarding the slip rate and the recurrence interval on the Whakatane Fault is presented on Table 3.1. The new data deriving from this study, which is part of the ongoing PhD study, appear to be as follows:

The average dextral displacement recorded on the spurs is 40 m whereas the average minimum vertical component appears to be in the order of 75m. The estimation of the vertical displacement is based on stratigraphic (not topographic) piercing points. Thus, the minimum dextral slip rate is 1mm/yr (based on a 40,000 year age of the displaced feature) and the maximum slip rate is 2 mm/yr (based on a 20,000 year age of the displaced feature). Using the same age span, the minimum vertical slip-rate of the fault will range between 1.9 and 3.9mm/yr. The maximum vertical slip-rate will be > 3.9 mm/yr. Thus, the net slip-rate on the Pukehoko section of the fault will range between 2.2-4.4 mm/yr. Estimates of the recurrence interval on the Whakatane Fault are based on a net slip in the order of 88.3m and a single event fault displacement ranging between 4 - 6m. Thus, the recurrence interval on this section of the fault appears to range between 1140-2230 years. These results are preliminary and may be refined as more detailed work is carried out as part of the on going PhD study by Vasso Mouslopoulou.

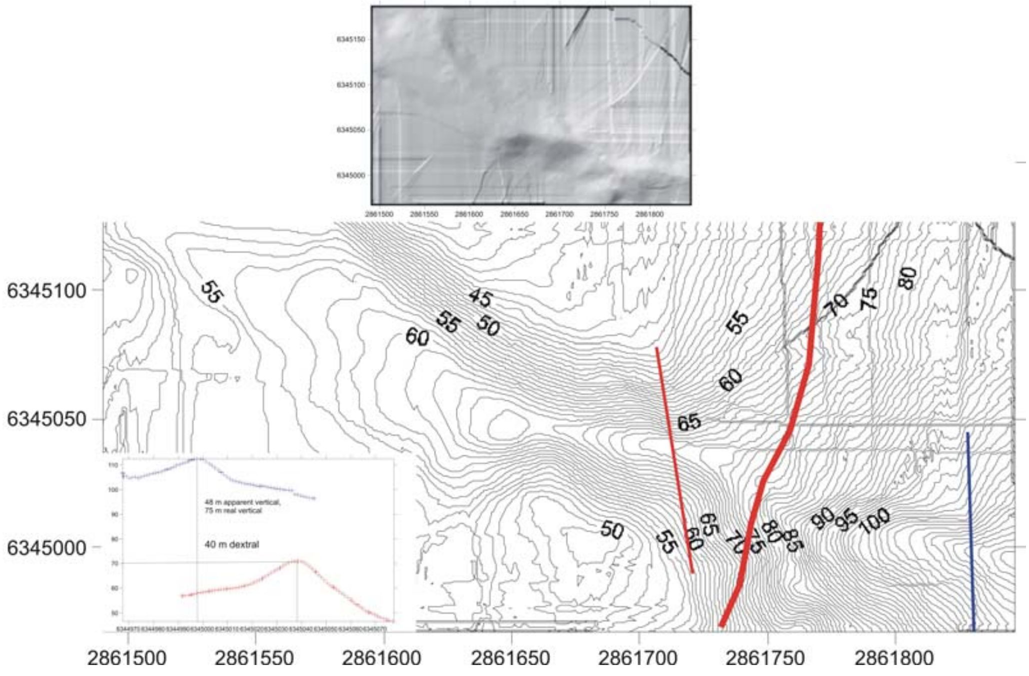


Figure 3.2 A ridge which has been offset by repeated earthquakes on the Whakatane Fault at Pukehoko The micro-topographic map was compiled from RTK-survey data. It shows the ridge displaced by ±40m at the solid red line fault. Blue and red cross sections each side of the fault show the magnitude of the lateral (strike slip) fault offset. The shaded relief map also shows the offset ridge.

Table 3.1 Up to date summary of the dextral, the vertical, the net Slip Rate and the Recurrence Interval on the northern end of the Whakatane Fault.

Whakatane Fault				
Dextral Slip Rate(mm/yr)	**Vertical Slip Rate(mm/yr)**	**Net Slip(mm/yr)**	**Recurrence Interval (y)**	**References**
1 -2 mm/yr			1000-3150	Beanaland, 1989
0,8 mm/yr				Beanland, 1995
1 mm/yr			1000-3000	New Matahina Report, 1997
			3500	Stirling et al., 2000
	1.5 ±0.6 (Min) - 2.3± 0.9 (Max)		no data	NIWA report, 2003
1 - 2 mm/yr	1.9 -3.9 (Min)	2.2 - 4,4 mm/yr	1140-2230	Mouslopoulou,2003*
*** Work in progress**				

3.2 Offshore faults – the Whakatane Fault

The offshore faulting in the Bay of Plenty has been comprehensively surveyed using sea-bourn seismic profiling over the last several years as part of the NZ research activities by NIWA. As a result the detailed offshore fault locations are better defined than they are onshore. However, since this work is not yet published, GNS commissioned NIWA to provide a report on the offshore extension of the Whakatane Fault as part of this study. The report provided by NIWA is reproduced in full here as Appendix 1.

In summary the Keepa Fault shown in Appendix 1 Figure 3, is determined to be the probable offshore extension of the Whakatane Fault. The Keepa Fault displays the largest offset of the submarine post-glacial surface and accommodates most of the movement of the three nearby faults in the coastal zone, having an observed 21.1m plus or minus 4.2m vertical offset that yields a 2.3mm plus or minus 0.9 mm/year vertical slip rate. This slip rate is comparable with the preliminary slip rate for the onshore Whakatane Fault determined by Mouslopoulou (Table 3.1 above).

The location of the Whakatane Fault through the urban area (Figure 2.4) can been derived for this study by drawing a straight line along the eastern side of the valley and extending this through the urban area, or by linking with a curved line the known closest onshore fault trace at Pukehoko with closest offshore trace of the Keepa Fault. We recognise that in nature faults deviate to some extent from a straight line and their scarp is not always a continuous line and can step sideways some distance (see Appendix 1, Figure 1). Thus the line of the Whakatane Fault through the urban area is inferred and has not been located. For this reason the fault location shown on Figure 2.4 is represented as dashed lines and the actual location of the fault is unknown, but this is our best estimate of its location at this stage. During an earthquake on it the fault is most likely to rupture to the surface forming a 2 to 3m scarp with relative down-throw on the west. It is therefore important for planning purposed to be able to locate the fault as accurately as possible. Hence we recommend subsurface geophysical investigations in the urban area to better locate the fault.

The subsurface Cone Penetrometer investigations carried out for this microzoning study were not able to confirm the location of the fault through the urban area, although they may suggest its presence. Additional work such as microgravity, seismic profiles and/or ground penetrating radar on profiles through the urban area may be effective in definitely establishing the location of the fault.

The other offshore faults located by NIWA (Appendix 1, Figure 1) are potential sources of rupture and strong earthquake shaking. They vividly illustrate the dynamic, active nature of the region.

4.0 GEOTECHNICAL INVESTIGATIONS

4.1 Introduction

The earthquake shaking response of a site is dependant on the magnitude and location of the causative earthquake and on the geotechnical properties of the layers of sub-surface materials. Information on the distribution and geotechnical properties of sub-surface materials in the Whakatane area has been obtained from a number of sources, including:

- File searching, particularly of building and construction records at the Whakatane District Council and Environment Bay of Plenty;
- Published technical reports (e.g. Christensen, 1995);
- Investigations carried out specifically for this project including:
- Nakamura survey;
- Cone penetration tests (CPT) and
- seismic cone penetration tests (SCPT) sub-surface probing at selected sites.

4.2 Nakamura survey data

For this technique, ambient or background ground vibrations at a chosen site are recorded on a portable seismograph. The data is then processed using the Nakamura method (see Appendix 2 for a detailed description of the Nakamura method and results obtained). This enables the potential resonance at a site to be evaluated. The value of the Nakamura technique is that micro tremor data on the response of many sites can be quickly gathered in the field, then analysed to assess the resonant characteristics of the sites. The flexibility of the technique allows it to be used as a screening method to identify which areas may or may not be susceptible to the amplification of earthquake ground shaking.

When there is a distinct peak to trough on the Nakamura plots (Appendix 2) the method gives a good estimate of the natural frequency of a resonant site, and an indication of amplification. Provided that the local geology is simple, the Nakamura method can be used with confidence to locate highly resonant areas where a widespread uniform soft or weak layer has an abrupt interface with firmer material, but is not easy to interpret when the sub-surface geology is complex.

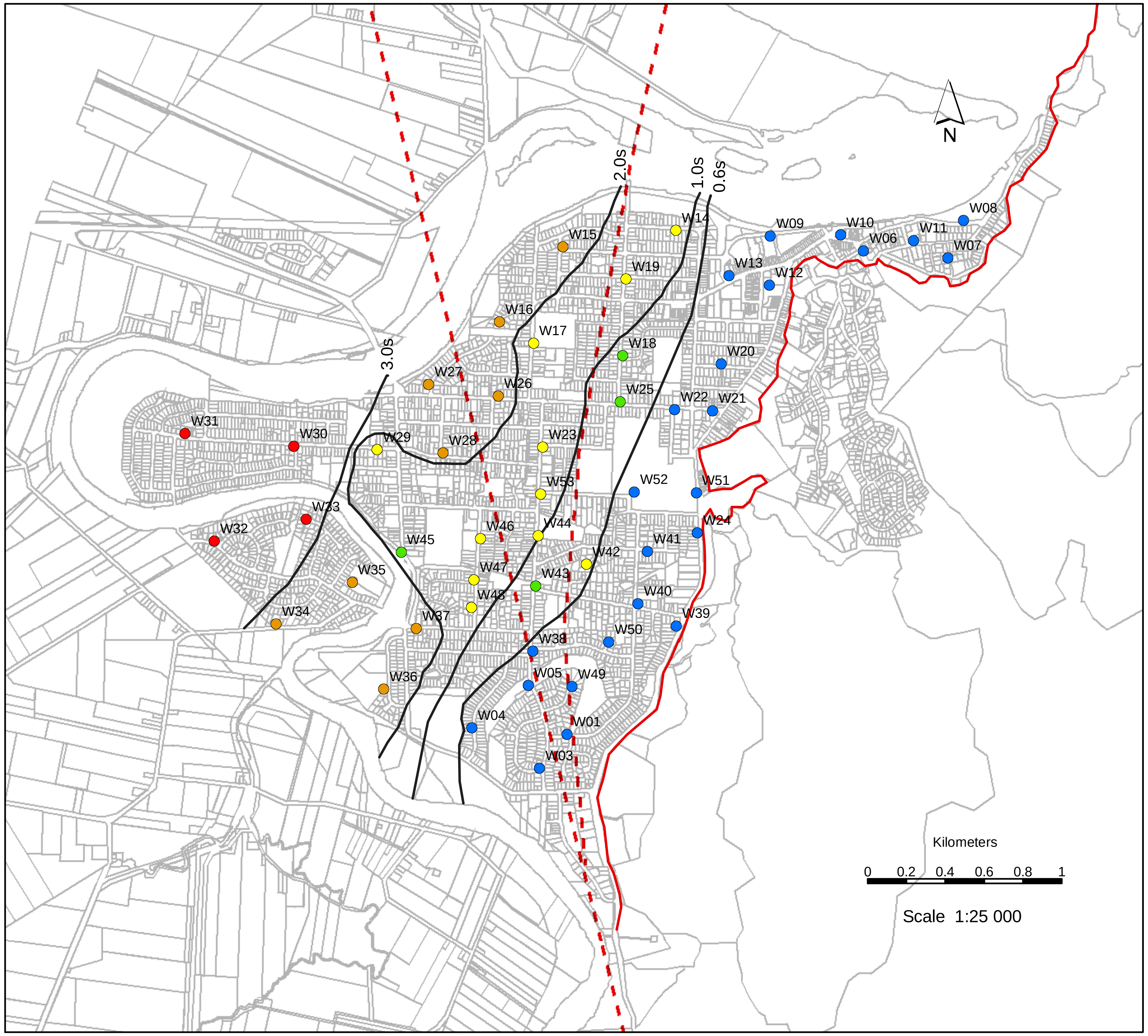


FIGURE:	Figure 4.1
PROJECT:	Whakatane Microzoning
TITLE:	Nakamura data contoured for natural site period.
DATE:	January 2004
DRAFTED BY:	J. Hoverd
PROJECT NO.:	430W1029
CR:	
EXPLANATION:	Nakamura data from Table 4.1 has been contoured for site period in intervals of 0.6, 1.0, 2.0, and 3.0 seconds. No data is available for the hill area (east of the cliff-line) Base Map: Whakatane District cadastral data.
LEGEND	Site period groups ● Site period > 3.0 s ● Site period 2.0 - 3.0 ● Site period 1.0 - 2.0 s ● Site period 0.6 - 1.0 s ● Site period 0.0 - 0.6 s — Site period contours — Base of former coastal cliff - - - Estimated fault location

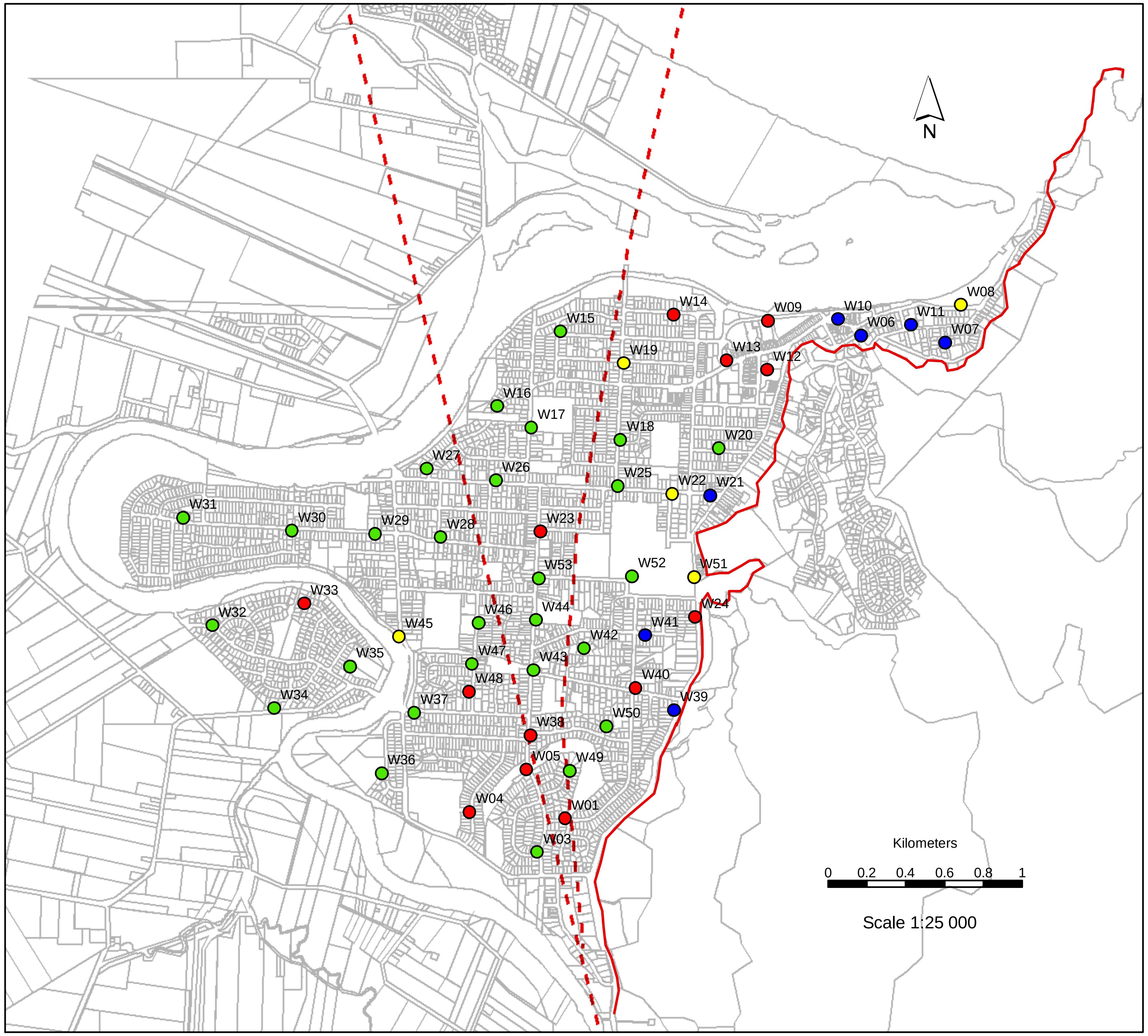


FIGURE:	A2 - 1
PROJECT:	Whakatane Microzoning
TITLE:	Nakamura results in Whakatane grouped according to ground shaking amplification potential.
DATE:	January 2004
DRAFTED BY:	J. Hoverd
PROJECT NO.:	430W1029
CR:	
EXPLANATION:	Grouping based on analysis of form of HVSR plots: 1. HVSR ratio <0.7 Hz at high frequencies (will amplify); 2. HVSR ratio moderately low (>0.7 Hz) at high frequencies with peak and trough (will amplify); 3. HVSR ratio moderately low at high frequencies (>0.7 Hz) with peak and possible trough (most likely amplify); 4. Resonant peak at sufficiently high frequency (>3.7 Hz) that trough cannot be seen (probably amplify). Base Map: Whakatane District cadastral data
LEGEND	Amplification Groups 🔴 1 🟡 2 🟢 3 🔵 4 - - - Estimated fault location — Base of former coastal cliff

The Nakamura processing, or horizontal to vertical spectral ratio (HVSR) plots from the 53 sites at Whakatane where micro-tremor measurements were taken (Figure 4-1), fall into several natural categories. A large proportion (80%) of the HVSR plots are characteristic of amplifying sites with soft or weak soils, as listed below.

1. There are 13 sites for which HVSR falls to below 1 at high frequencies. These sites will amplify and are marked as red dots on Figure A2-1). They are:

   W01, W04, W05
   W09 - drops to 0.38, possible peak at 3.7Hz, no trough
   W12 - drops to 0.34, peak at 3.9Hz, trough at 7.9 Hz
   W13 - drops to 0.31
   W14 - drops to 0.66, peaks at 0.7Hz, 2.2Hz, no trough
   W23 - drops to 0.48, peaks at 0.75Hz, 0.95Hz
   W24 - drops to 0.27, peak at 2.9Hz
   W33 - drops to 0.54, peaks at 0.31Hz, ~1Hz
   W38 - drops to 0.45, peak at 2.0, trough at 6.0Hz
   W40 - drops to 0.4, peak at 3Hz, trough at 6.4Hz
   W48 - drops to 0.58, peak at 0.72Hz, 3.0Hz, trough at 7.3Hz

2. There are 5 sites which have a peak and a trough, but for which the HVSR falls only to a moderately low value at high frequencies. These sites will amplify and are marked as yellow dots on Figure A2-1.

   W08 - peak at 4.7Hz, trough at 9.1Hz
   W19 - peak at 0.62Hz, trough at 7.0Hz (peak and trough not associated)
   W22 - peak at 4.0Hz, trough at 7.6Hz
   W45 - peak at 1.2Hz, trough at 6.6Hz (peak and trough not associated)
   W51 - peak at 4.6Hz, trough at 8.9Hz

3. There are 25 sites which have a peak and a possible trough, but for which the HVSR falls only to a moderately low value at high frequencies. These sites will most likely amplify and are marked as green dots on Figure A2-1.

   W15 - peaks at 0.46Hz, 2.2Hz, possible trough 4.6Hz
   W16 - peaks at 0.46Hz, 1.6Hz, possible trough 8Hz
   W17 - peak at 0.54Hz
   W18 - peak at 1.1Hz, possible trough 4.9Hz
   W20 - peak at 3.7Hz, possible trough 7.7Hz
   W25 - peak at 1.4Hz, possible trough 4.4Hz
   W26 - peak at 0.5Hz, possible trough 4.2Hz
   W27 - peak at 0.4Hz, possible trough 4.5Hz

W28 - peak at 0.45Hz, possible trough 3.4Hz
W29 - peak at 0.76Hz, possible trough 2.3Hz
W30 - peak at 0.31Hz, possible trough 2.8Hz
W31 - peak at 0.28Hz, 1.4Hz, possible trough 2.8Hz
W32 - peak at 0.3Hz, 1.4Hz, possible trough 2.8Hz
W34 - peak at 0.36Hz, 1.2Hz, possible trough 7.2Hz
W35 - peak at 0.38Hz, 1.0Hz, possible trough 2.7Hz
W36 - peak at 0.4Hz, 1.1Hz, possible trough 2.8Hz
W37 - peak at 0.46, 1.4Hz, possible trough 3Hz
W42 - peak at 0.9Hz, possible trough at 5.2Hz
W43 - peak at 1.1Hz, possible trough at 4.9Hz
W44 - peak at 1.0Hz, possible trough at 4.8Hz
W46 - peak at 0.7Hz, 2.4Hz
W47 - peak at 0.72, 2.5Hz, possible trough 6.4Hz
W49 - peak at 2.6Hz, possible trough 6.3Hz
W50 - peak at 3.5Hz, possible trough 7Hz
W52 - peak at 2.7Hz, possible trough 5.5Hz
W53 - peak at 0.9Hz, possible trough 7.5Hz

4. There are 6 sites which have a resonant peak at a sufficiently high frequency that a trough, or a drop off at high frequency, cannot be seen even though it may exist. All these sites are probably amplifiers and are marked as blue dots on Figure A2-1.

W07 - peak at 7Hz
W10 - peak at 4.6Hz, falling off rapidly above 8Hz
W11 - peak at 5.2Hz, falling off rapidly above 8Hz
W21 - peak at 5.2Hz, falling off rapidly above 8Hz
W39 - peak at 5Hz, falling off rapidly above 8Hz
W41 - peak at 3.7Hz, falling off rapidly above 6Hz

5. Some sites have a noticeable peak at a low frequency. These are listed separately even though they appear in the earlier groups.

W14, W15, W16, W17, W18, W19, W23, W22 – possibly, W24 – possibly, W26, W27, W28, W29, W30, W31, W32, W33, W34, W35, W36, W37 – possibly, W43, W44, W46, W47, W48 – possibly, W53

The Nakamura data has been grouped in Table 4.1.

Site No.	Primary peak (Hz)	Second peak (Hz)	HVSR form grouping	Primary peak (sec)	Second peak (sec)	Definite LFP (sec)	Possible LFP (sec)	No LFP (sec)
1	4		1	0.25				0.25
2			5					
3	3.4		3	0.29				0.29
4	3.4		1	0.29				0.29
5	2.2		1	0.45				0.45
6	5.6		4	0.18				0.18
7	7		4	0.14				0.14
8	4.7		2	0.21				0.21
9	3.7		1	0.27				0.27
10	4.6		4	0.22				0.22
11	5.2		4	0.19				0.19
12	3.9		1	0.26				0.26
13			1					
14	0.7	2.2	1	1.43	0.45	1.43		
15	0.46	2.2	3	2.17	0.45	2.17		
16	0.46	1.6	3	2.17	0.63	2.17		
17	0.54		3	1.85		1.85		
18	1.1		3	0.91		0.91		
19	0.62		2	1.61		1.61		
20	3.7		3	0.27				0.27
21	5.2		4	0.19				0.19
22	4		2	0.25			0.25	
23	0.75	0.95	1	1.33	1.05	1.33		
24	2.9		1	0.34			0.34	
25	1.4		3	0.71				0.71
26	0.5		3	2.00		2.00		
27	0.4		3	2.50		2.50		
28	0.45		3	2.22		2.22		
29	0.76		3	1.32		1.32		
30	0.31		3	3.23		3.23		
31	0.28	1.4	3	3.57	0.71	3.57		
32	0.3	1.4	3	3.33	0.71	3.33		
33	0.31	1	1	3.23	1.00	3.23		
34	0.36	1.2	3	2.78	0.83	2.78		
35	0.38	1	3	2.63	1.00	2.63		
36	0.4	1.1	3	2.50	0.91	2.50		
37	0.46	1.4	3	2.17	0.71		2.17	
38	2		1	0.50				0.50
39	5		4	0.20				0.20
40	3		1	0.33				0.33
41	3.7		4	0.27				0.27
42	0.9		3	1.11				1.11
43	1.1		3	0.91		0.91		
44	1		3	1.00		1.00		
45	1.2		2	0.83				0.83
46	0.7	2.4	3	1.43	0.42	1.43		
47	0.72	2.5	3	1.39	0.40	1.39		
48	0.72	3	1	1.39	0.33		1.39	
49	2.6		3	0.38				0.38
50	3.5		3	0.29				0.29
51	4.6		2	0.22				0.22
52	2.7		3	0.37				0.37
53	0.9		3	1.11		1.11		

Table 4.1 Summary of micro-tremor data processed using the Nakamura technique. The definitions of the categories used for grouping the data are given in the text. The initial values are given in terms of the frequency of the peak in hertz (Hz), but for the analysis of the low frequency peaks (LFP) the data is converted to period (seconds). The site No. locations and the contoured site period bands are shown on Figure 4.1.

To assign ground class to a site, one parameter that can be used is the site period (Table 4.3). To achieve this each of the Nakamura peak frequencies (Hz) has been converted to its reciprocal ground period (sec) for mapping purposes (Table 4.1).

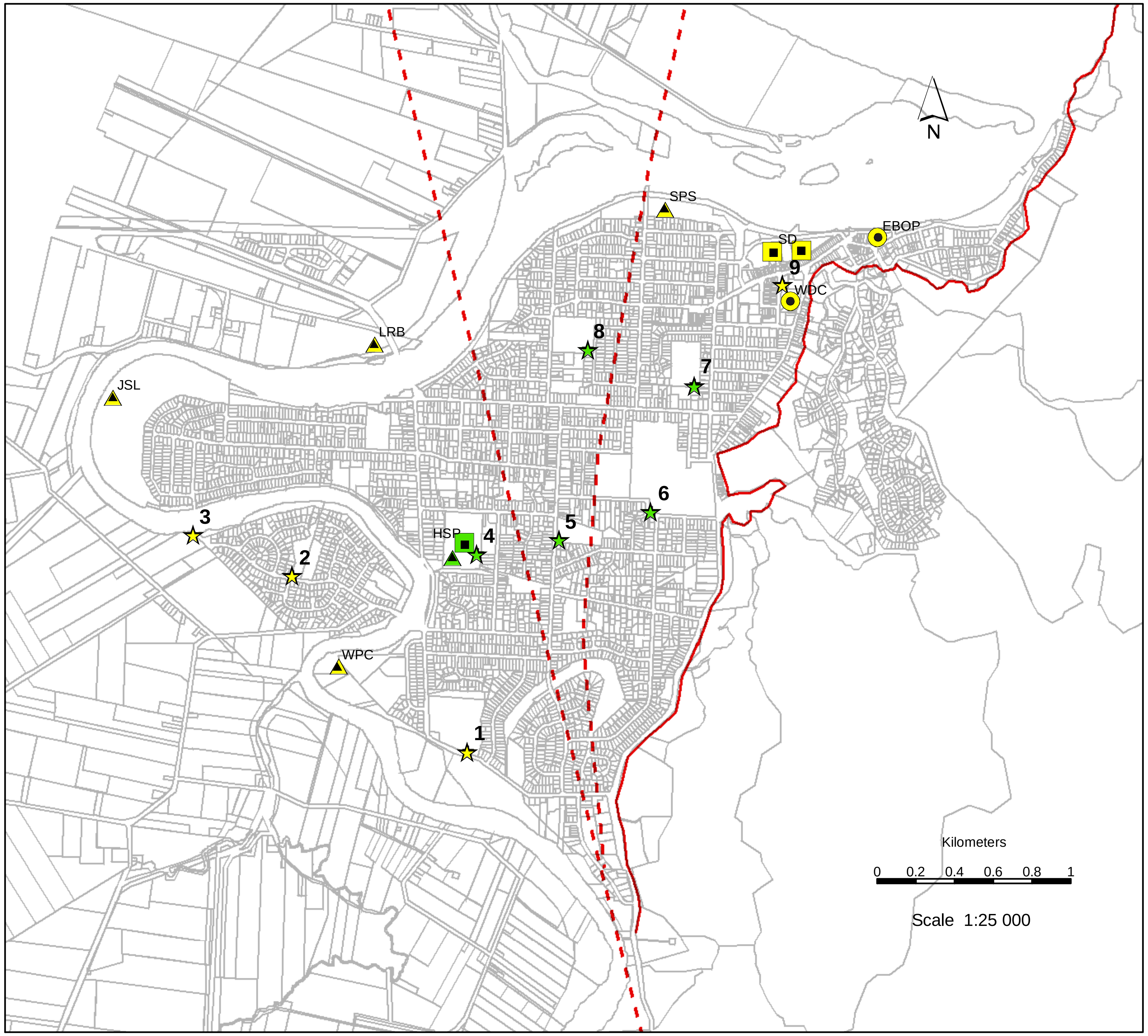


FIGURE:	Figure 4.2
PROJECT:	Whakatane Microzoning
TITLE:	CPT/SCPT locations from this report and previous investigations.
DATE:	January 2004
DRAFTED BY:	J. Hoverd
PROJECT NO.:	430W1029
CR:	
EXPLANATION:	Data sources as per Table 4.2. Base Map: Whakatane District cadastral data.
LEGEND	🟨 Liquefaction probable 🟩 Liquefaction unlikely ▲ CPT Christensen (1995) ● CPT other sources ■ CPT Tonkin & Taylor (various projects) ★ SCPT/CPT test site (this report) ― Base of former coastal cliff ╌ Estimated fault location

When the data showing the presence or absence of a peak at low frequencies are plotted a clear pattern is discernable (Figure 4.1). All the sites without a low frequency peak plot within 6 - 800 metres of the former coastal cliffs. If the frequencies are converted to period, all sites within this zone have a natural site period of less than 0.6 seconds. The sites with a peak at low frequency (<1.5 Hz) are all over 500 metres from the former coastal cliffs. All the sites that have a secondary peak are also within this zone. The quality of the data is good and allows the frequency/period of amplified ground shaking for Whakatane to be contoured with confidence (Figure 4.1). The first contour line is placed at a period of 0.6 seconds as this is a boundary condition for differentiating between ground class C (shallow "stiff" soils) and ground class D (deep or "soft" soils). Thereafter contours are at intervals of one second (i.e. at periods of 1, 2, and 3 seconds).

The increase in site period across Whakatane appears to reflect an increase in the total depth of soil away from the cliffs. The ground class as determined by Nakamura methods is essentially in agreement with the ground class determined using seismic cone penetrometer data (see below) taking into account that the SCPT data is from the soft or weak surface layer and the Nakamura data reflects both the surface layer and deeper sediments.

Direct evidence for locating the position of the Whakatane Fault has not been identified in the data from these groupings. However, the lower frequencies associated with the greater depth of the top layer to the west may indicate displacement of the basal surface of this layer across the Whakatane Fault.

4.3 SCPT and CPT data

Seismic cone penetrometer (SCPT) and cone penetrometer tests (CPT) tests were carried out at 9 new sites in Whakatane for this study Figure 4.2). Earlier work that has been carried out in the urban area has been included (Table 4.2). Descriptions of the SCPT and CPT methods and the data obtained are in Appendix 3.

4.3.1 CPT data

Cone penetrometer test data was obtained from a number of sources, such as Christensen (1995) and file searching at the Whakatane District Council and Environment Bay of Plenty. This data is summarized in Table 4-2 along with the data from CPT investigations undertaken for this project. The CPT sites are shown on Figure 4-2.

The CPT data confirms the presence of a weak layer in the urban area of Whakatane that is built on the flood plain of the Whakatane River. The data shows that this weak layer varies in thickness from 1 to 10 m (usually 4 to 8 m) and generally consists of fine-grained cohesionless materials (sand and silt). By comparing the depth of the layer with the depth to the water table, an assessment can be made of the likelihood of liquefaction occurring. The deeper layers below this surface layer have a high point resistance indicating that they are dense and will not liquefy. For liquefaction to occur the soil must be loose, granular (fine grained sands and silts with a uniform grain size) that are saturated (below the water table).

Location	Figure 4.2 code	Data Source	Hole no	Water level	Weak layer	Liquefiable
Awatapu Drive	3	Beetham et al 2003	SCPT1	3m	7.2m	yes
James Street Loop	JSL	Christensen 1995	JSL001	1m	6.2m	yes
James Street Loop	JSL	Christensen 1995	JSL002	0.8m	6.4m	yes
James Street Loop	JSL	Christensen 1995	JSL003	1.8m	8.2m	yes
James Street Loop	JSL	Christensen 1995	JSL004		7.8m	yes
James Street Loop	JSL	Christensen 1995	JSL005	1.9m	10.3m	yes
James Street Loop	JSL	Christensen 1995	JSL006		10mm	yes
James Street Loop	JSL	Christensen 1995	JSL007	1.2m	7	yes
James Street Loop	JSL	Christensen 1995	JSL008	1.2m	6.7m	yes
Awatapu Park	2	Beetham et al 2004	SCPT3	3m	5m	yes
Hospital	4	Beetham et al 2004	SCPT4	3m	6m	no
Hospital	HSP	Christensen 1995	HSP001	>4.0m	3.5m	no
Hospital	HSP	Christensen 1995	HSP002	>4.0m	2.8m	no
Hospital	HSP	Tonkin & Taylor, 1988	CP1	4.4m	3m	no
Hospital	HSP	Tonkin & Taylor, 1988	CP2	4.4m	2.6m	no
Hospital	HSP	Tonkin & Taylor, 1988	CP3	4.4m	3.2m	no
Hospital	HSP	Tonkin & Taylor, 1988	CP4	4.4m	3.5m	no
Hospital	HSP	Tonkin & Taylor, 1988	CP5	4.4m	2.6m	no
Hospital	HSP	Tonkin & Taylor, 1988	BH1	4.4m		no
St Joseph School	5	Beetham et al 2004	SCPT5	3m	2.4m	no
Warren Park	8	Beetham et al 2004	SCPT6	3m	3.8m	no
Apanui School	7	Beetham et al 2004	SCPT7	3m	3.4m	no
Peace Park	9	Beetham et al 2004	SCPT8	3m	7.8m	yes
Pumping station	SPS	Christensen 1995	SPS001	1.4m	8.3m	yes
Trident High School	1	Beetham et al 2004	SCPT9	3m	10.5m	yes
Whakatane Pony Club	WPC	Christensen 1995	WPC001	2.4m	8.6m	yes
Whakatane Pony Club	WPC	Christensen 1995	WPC002	2.2m	8.3m	yes
Whakatane Pony Club	WPC	Christensen 1995	WPC003	1.9m	6.8m	yes
Whakatane Pony Club	WPC	Christensen 1995	WPC004	4m	7.6m	yes
Rex Morpeth Park	6	Barker 1995	SCPT11	?	4m	no
Landing Road Bridge	LRB	Christensen 1995	LRB001		5.4m	yes
Landing Road Bridge	LRB	Christensen 1995	LRB002		4.8m	yes
Landing Road Bridge	LRB	Christensen 1995	LRB003		6.1m	yes
Landing Road Bridge	LRB	Christensen 1995	LRB004		6.5m	yes
Landing Road Bridge	LRB	Christensen 1995	LRB005		7.3m	yes
Landing Road Bridge	LRB	Christensen 1995	LRB006		6.5m	yes
Landing Road Bridge	LRB	Christensen 1995	LRB007	1m	6.3m	yes
Landing Road Bridge	LRB	Christensen 1995	LRB008/9		6.5m	yes
Landing Road Bridge	LRB	Christensen 1995	LRB010		6.1m	yes
Landing Road Bridge	LRB	Christensen 1995	LRB011		5.3m	yes
Landing Road Bridge	LRB	Christensen 1995	LRB012		8.1m	yes
Landing Road Bridge	LRB	Christensen 1995	LRB013		7.5m	yes
New World	NW	Tonkin & Taylor, 2002				yes
Strand Development	SD	Tonkin & Taylor, 2002	1	2.5m		yes
Strand Development	SD	Tonkin & Taylor	2	2.1m		yes
Strand Development	SD	Tonkin & Taylor	3	2.1m		yes
Strand Development	SD	Tonkin & Taylor	4	2.1m		yes
Strand Development	SD	Tonkin & Taylor	5	dry		no
Strand Development	SD	Tonkin & Taylor	6	1.8m		yes
Strand Development	SD	Tonkin & Taylor	CP4	2m	6.5m	yes
Strand Development	SD	Tonkin & Taylor	CP5	2m	5.5m	yes
Strand Development	SD	Tonkin & Taylor	CP6	2m	6m	yes
Strand Development	SD	Tonkin & Taylor	CP11	2m	6m	yes
Whakatane DC	WDC	Murray-North			6m	yes
EBOP	EBOP	BH Consultants	CPT1		5m	yes
EBOP	EBOP	BH Consultants	CPT2		4m	yes
EBOP	EBOP	BH Consultants	CPT3		5m	yes
EBOP	EBOP	BH Consultants	CPT4		1m	no
EBOP	EBOP	BH Consultants	CPT5		5m	yes
EBOP	EBOP	BH Consultants	CPT6		4m	yes

Table 4.2 Summary of CPT data from reports, files and work undertaken for this project. Site locations are shown on Figure 4-2. Note Beetham et al 2004 is this study.

4.3.2 SCPT data

Eight sites were selected for probing with both seismic cone penetrometer tests (SCPT) and CPT. In addition SCPT and CPT data from one previous test site at Rex Morpeth Park by Barker in 1995) are included. The test locations are shown on Figure 4.2 and the full results are presented in Appendix 3. A summary of the results of SCPT and CPT probing, as well as additional data obtained from reports and file searching, is presented in Table 4.2.

The earthquake-amplifying behaviour of a soft or weak site is primarily controlled by the shear wave velocity profile of the site. This primary control is modified by the lateral extent of the deposit, by the soil type and its depth. A wide basin can lead to long duration shaking, but a noncohesive soil can reduce amplification. The soils at Whakatane are clearly non-cohesive and are classified as fine grained sands and silts. In general, or experience indicates the Whakatane SCPT profiles show that amplification of earthquake shaking is likely, with many of the sites being comparable with the lower Hutt Valley. However none of the sites approaches the extreme nature of Wainuiomata or the Valley of Mexico, which are known to have soft cohesive soils.

Of the nine sites, three (Apanui School, Awatapu Park and Trident High School) show clear reflections from some depth. A reflection implies a velocity contrast and therefore a resonance, so the natural frequencies of these sites may be assessed (summarised in Table 4.5). Two other sites (Warren Park and Peace Park) each have a surface layer which is well constrained by CPT data, and for which the likely resonant frequency and the US National Earthquakes Hazards Reduction Programme (NEHRP) category may be calculated. The remaining three sites (St Joseph’s School, Whakatane Hospital and Awatapu Drive) do not have an SCPT reflection, nor is it clear that a CPT-bounded layer exists. In these circumstances it is only possible to calculate bounding values for resonant frequency and NEHRP category. At Rex Morpeth Park (probed in 1995) tip resistance increased steadily with depth, and together with the accumulated side friction, prevented penetration below 7.4m. No estimate of layer thickness may be made, and there were no reflections in the SCPT trace.

4.4 Nakamura/SCPT comparisons for Whakatane

Of the nine SCPT sites, five stand out by having either or both an identifiable basement, or upward-reflected waves. One (Peace Park) stands out in view of its low (114m/s) velocity, albeit to only a shallow (8m) depth. The appearance or non-appearance of reflections on the SCPT plots does not appear to indicate higher amplification effects since, in terms of Nakamura ratio plots, there appear to be no differences between sites having either or both of an identifiable basement, or upward-reflected waves, and the rest of the sites.

However, the low velocity site of Peace Park lies within a region where the Nakamura ratio falls to below 1 at high frequencies (these sites will amplify). Thus it appears that for Whakatane, the 13 sites identified as type 1 (red dots on the map Figure A2.1) are associated with low velocity and hence amplifying soils. Those red dot sites where the low velocity material may be in a thicker layer (No's 1 ,4, 5, 23, 24, 33, 38, 40, 48) will have lower natural frequencies, and will be associated with higher MM values than the shallower ones at sites 9, 12, 13 and 14 in the CBD area.

In combination, the Nakamura and SCPT data identify a surface layer with a period in the range 0.14 - 0.50 seconds near the former greywacke cliffs and with a period in the range 0.37 - 1.05 seconds away from the cliffs. The SCPT data shows the near cliff layer with a period in the range 0.15 - 0.69 seconds.

4.5 Ground class map

Local geological deposits, or ground conditions, are well known for their ability to influence the nature of shaking a site experiences during an earthquake. Strong ground shaking is the most pervasive earthquake hazard, and accounts, either directly or indirectly, for most of the damage, and consequent loss of life, resulting from an earthquake.

This has been recognised and incorporated into the definitions used for ground shaking amplification classes used in the draft NZ/Australia Loadings Code, given in Tables 4.3 and 4.4 below.

Table 4.3 Ground class definitions used in the draft NZ loadings code. For NZ, the two rock Ground Classes A and B (strong and weak rock) are assigned the same spectra and are not separated.

Ground Class	Geological description	Engineering description
A	Strong rock	Sites with strong rock (i.e. material with a compressive strength of 50MPa or greater) at the surface, or sites with a soil layer of thickness not exceeding 3 metres overlying rock. Shear wave velocities of greater than 1500 m/s.
B	Weak rock	Sites with weak rock (i.e. material with a compressive strength between 1MPa and 50Mpa) at the surface, or sites with a soil layer of thickness not exceeding 3 metres overlying rock.
C	Shallow stiff soil	Soil sites with depths of soils less than the limits defined in Table 4-4.
D	Deep or "soft" soil	Soil sites with periods greater than 0.6s, or with depths of soil greater than those defined in Table 4-5, but excluding Class E sites.
E	"Very soft" soil	Sites with more than a few metres of very soft cohesive soils with undrained shear strength less than 12.5kPa, or with about 10m or more of soil with shear-wave velocities less than 150m/s, or with about 10m or greater thickness of very high plasticity clays with plasticity index PI>75.

(Note that in New Zealand and for this report, the strong and weak rock, Ground Classes A and B are not distinguished and are lumped together in a "rock" Ground Class).

Table 4.4 Depth limits for ground classes C and D from the draft NZ loadings code.

Soil type and description		Depth of soil (m)
Cohesive soil	*Representative undrained shear strengths (kPa)*	
Soft	12.5-25	20
Firm	25-50	25
Stiff	50-100	40
Very stiff or hard	100-500	60
Cohesionless soil	*Representative SPT (N) values*	
Loose	4-10	40
Medium dense	10-30	45
Dense	30-50	55
Very dense	>50	60
Gravels	>30	100
Notes: Depths no greater than those above qualify as Class C, greater depths qualify as Class D, except where Class E criteria apply. For layered sites, the ratios of the depth of each soil type to the limits of the table should be added, with a sum not exceeding 1.0 corresponding to Class C and greater sums to Class D.		

Ground class can be assessed using a number of criteria, such as: NEHRP; the NZ draft loadings code using both the geological model and site period; Tables 4.3 & 4.4; and the Nakamura results obtained for this study (Table 4.1). The variation in ground class between the different schemes (Table 4.5) is resolved as follows:

- For sites 3, 4, 6 & 9 all the techniques yield the same result – Ground Class C & D.
- For sites 2 & 8 the site periods determined by SCPT and Nakamura result in different ground classes being assigned. This is attributed to the SCPT sites giving a site period for the surface layer only, while the Nakamura results reflect a deeper sedimentary column. On this basis these two sites are assigned the ground class derived from the Nakamura results.
- For site 1 the period from SCPT is 0.6 seconds, the boundary between ground classes C and D. The geological model developed for Whakatane suggests that this site overlies deeper sediments on the downthrown side of the Whakatane Fault. It is therefore assigned to ground class D. (The shear wave velocity used by NEHRP to assign ground class is 30m/s greater than the NZ draft loadings code and on this basis the assignment of ground class E under NEHRP would actually be ground class D in the NZ code and is therefore ignored).
- For site 5 the geological model suggests ground class C, whereas NHERP suggests D. The Nakamura results yield a ground period less than 0.6 seconds, confirming that the ground class at this site is likely to be C.
- For site 7 the NZ draft loadings code (both the geological model and the SCPT derived site period) and the Nakamura results give a ground class of C. The NEHRP classification gives a ground class of D but as this is at odds with the other techniques (including SCPT derived site period) a ground class of C is assigned.

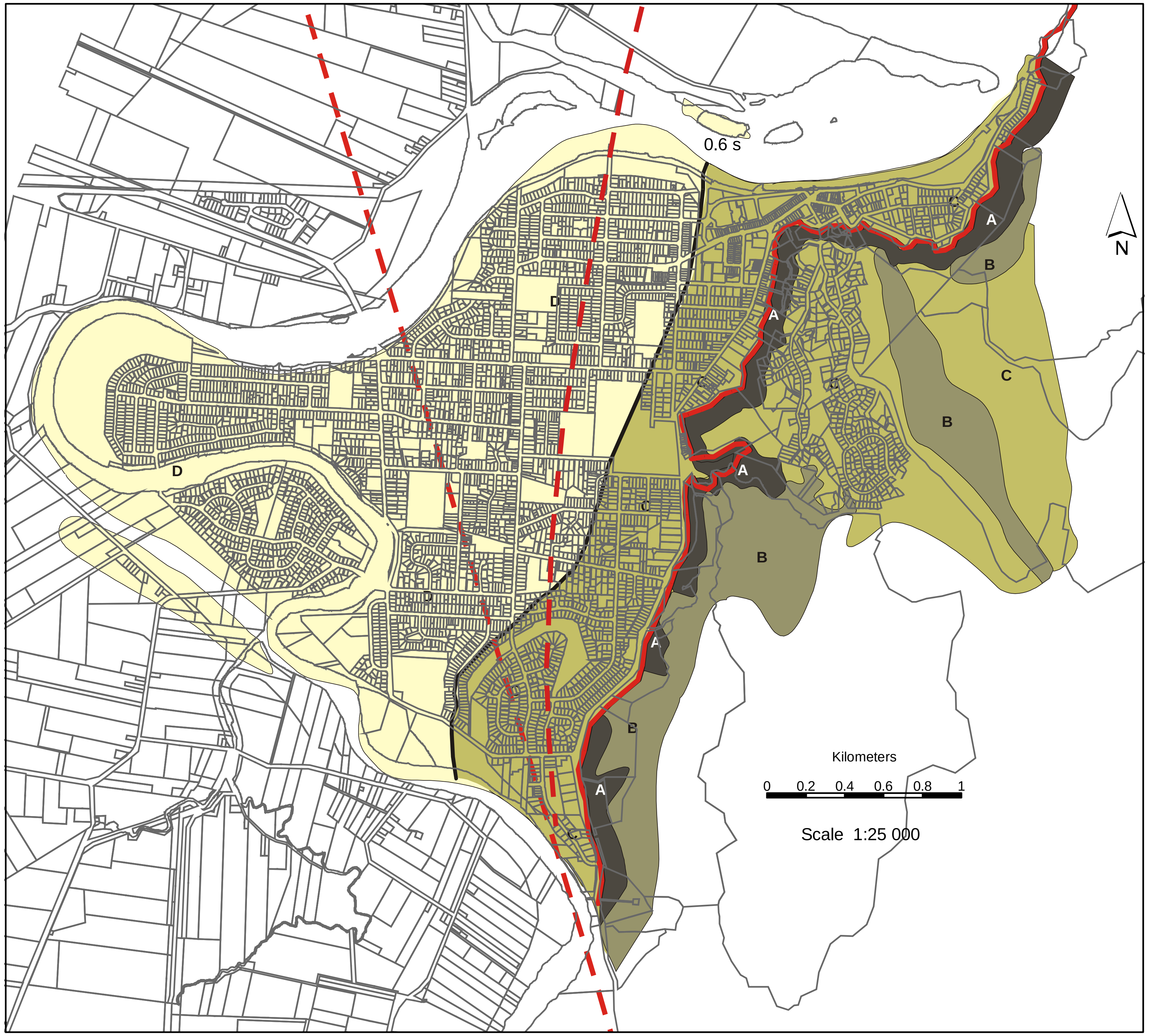


FIGURE:	Figure 4.3
PROJECT:	Whakatane Microzoning
TITLE:	Ground class map of the Whakatane Urban area.
DATE:	January 2004
DRAFTED BY:	J. Hoverd
PROJECT NO.:	430W1029
CR:	
EXPLANATION:	Ground classes defined as per the draft NZ Loadings Code. Base Map: Whakatane District cadastral data.
LEGEND	**A** Strong rock **B** Weak rock **C** Shallow, stiff soil **D** Deep, or soft soil NB: See text for explaination — Base of former coastal cliff - - - Estimated location of fault

Table 4.5 Derived ground class for the SCPT sites using NHERP, NZ code (site period (SP) or geological model (GM)) and Nakamura results (from this study).

Site No.	Site natural frequency -Hz (ground period seconds) estimated from SCPT			Shear wave velocity (m/s) for V_s30 estimated from SCPT			Ground Class Code from various sources				
	Min	Predicted	Max	Min.	Av.	Max.	NHERP	NZ code		From Naka-mura period	**Selected NZ code class**
								GM	SP		
1	1.45 (0.69)	1.66 (0.60)		168	176	185	"E"	D	C/D	C/D	**D**
2	1.44 (0.70)	1.94 (0.52)		156	197	232	"D"	D	C/D	D	**D**
3			2.90 (0.34)	204			"D"	D		D	**D**
4			3.70 (0.27)	162			"D"	D		D	**D**
5			6.60 (0.15)	175			"D"	C		D	**D**
6				205			"C"	C		C	**C**
7	1.84 (0.54)	2.58 (0.38)		151	217	283	"D"	C	C	C	**C**
8		2.00 (0.50)		152	199	238	"D"	C	C	D	**D**
9		3.20 (0.31)		120	240	370	"C/D"	C	C	C	**C**

Thus for each geological unit in the Whakatane a ground class has been assigned based on: the geological description; the depth to basement; and the geotechnical properties derived from the Nakamura and CPT/SCPT results (Tables 4.5 & 4.6).

Figure 4.3 shows the ground class map for the Whakatane area based on the geological map given in Figure 2.3 and the other data. Points to note are that on the hills, areas shown as greywacke are assumed to have less than 3 metres depth of soils (ground class B). Where the Lukes Farm Beds are present they are assigned to the rock class (ground class B). Where tephras and undifferentiated ignimbrites are mapped they are given a ground class of shallow soil as they are generally less than 20 metres thick (ground class C).

The geological units of the Whakatane River flood plain are generally assigned to the deep soil ground class (D) except where geotechnical information (e.g. Nakamura results) indicate that the soils are shallow (i.e. they have a site ground period of less than 0.6 seconds) where they are assigned to the shallow soil ground class (ground class C). The soils of the Whakatane River floodplain are shallow adjacent to the former coastal cliffs.

Table 4.6 Extended legend for geological map of the Whakatane Urban area (Figure 2.3). The units assigned a C/D ground class are divided either side of the 0.6 second ground period contour derived from the Nakamura data.

Geological Unit	**Sub-surface geology**	**Ground Class**	**Liq. Susc.**
Fill	1.5 m of sandy medium dense to dense gravel (FILL) overlying medium dense sands of estuarine and/or shallow marine origin. Also soft clays and loose silts and sands in upper 6 m in places.	C/D	3
Active overbank sediments	3-5 m of sands and silts overlying medium to dense sands. (0.3-1.5 m accumulation post 1886 – Tarawera eruption)	C/D	4
Protected overbank silts & sands	3-5 m of sands and silts overlying medium to dense sands. (0.3-1.5 m accumulation post 1886 – Tarawera eruption)	C/D	3
Meander troughs (protected)	3-5 m of peat, loose sand and silt overlying medium dense sand.	C/D	3
Dunes	0.5 m ash derived soils (Tarawera, Kaharoa and Taupo) over 5 m loose sand over 3 m medium dense sand (dunes) or 0.5 m ash derived soils and 3-4.5 m soft clay overlying medium dense sands (peat swamps).	C/D	0
Colluvium	2-6 m of soft clay, loose sand and pumice gravel overlying medium dense sand.	C	2
Tephras & Ohope Beds	0.6 m of young tephras (Tarawera, Kaharoa, Taupo pumice and Whakatane) over 15 m of Quaternary volcanic deposits (ashes and lapilli) over older Ohope Beds over greywacke	C	0
Greywacke	Highly to moderately weathered greywacke overlain by greywacke derived residual soils and colluvium and 2-3 m of older ashes (Whakatane and Rotoma).	B	0
Greywacke	Unweathered to moderately weathered, moderately strong to strong interbedded SANDSTONE & SILTSTONE, closely jointed rock mass.	A	0

The ground class implications for ground shaking behaviour are not a direct increase in felt intensity per se. Ground shaking behaviour relates to specific frequencies of shaking and the resultant greater damage to structures that have a natural period close to the amplified frequencies in each ground class. The structures at risk will therefore vary in the different ground classes.

4.6 Liquefaction susceptibility map

A liquefaction susceptibility model has been developed by GNS and calibrated using historical data. The model is used to produce maps which illustrate the general susceptibility of an area to liquefaction, if ground shaking above the triggering threshold were to occur. This threshold varies depending on the nature of the ground being shaken. In brief, materials that have a very high susceptibility have a low (generally MM7) triggering threshold, and materials that have a low susceptibility have a high (MM10) triggering threshold. At the triggering threshold for a particular unit the ground damage is generally minimal (liquefaction damage class 1 – see Table 4.7). The greater the level of shaking above the triggering threshold the greater the ground damage (Table 4.8) (*e.g.* for the very high susceptibility class, at MM10 the ground damage is likely to resemble the description of damage for liquefaction damage class 4).

In order to understand what the different levels of liquefaction susceptibility mean in terms of ground damage at different shaking intensities liquefaction damage classes are defined in terms of the manifest ground damage (Table 4-7). These are then used to build a matrix to describe the extent of liquefaction induced ground damage that will occur in the different susceptibility classes at different levels of shaking intensity (Table 4.8).

Liquefaction susceptibility ratings are as follows:
A "**very high**" rating is for areas where liquefaction phenomena are known to have occurred at a shaking intensity of MM7 during historical earthquakes a "high" rating is for areas where the occurrence of liquefaction phenomena has been initiated at a shaking intensity of MM8 during historical earthquakes.

A "moderate" rating is for areas where the occurrence of liquefaction phenomena has been initiated at a shaking intensity of MM9 during historical earthquakes.

A "**low**" rating is for areas where the occurrence of liquefaction phenomena has been initiated at a shaking intensity of MM10 during historical earthquakes.

A "**negligible**" rating is for units that are older than 15,000 years (the latest Pleistocene) and that have not exhibited signs of liquefaction phenomena during MM10 intensity shaking during historical earthquakes.

The model has been calibrated using historical examples of liquefaction during strong earthquake shaking. For example, the 1987 Edgecumbe earthquake resulted in a shaking intensity of MM8 in the western part of Whakatane (Landing Road Bridge, James Street and Awatapu areas) and MM7 elsewhere. The river edges in the MM8 zone experienced liquefaction consistent with liquefaction damage class 2. Away from the immediate river edges isolated sand boils were observed. In the MM7 zone the only liquefaction induced damage occurred in the immediate vicinity of the river bank (e.g. sewage pumping station).

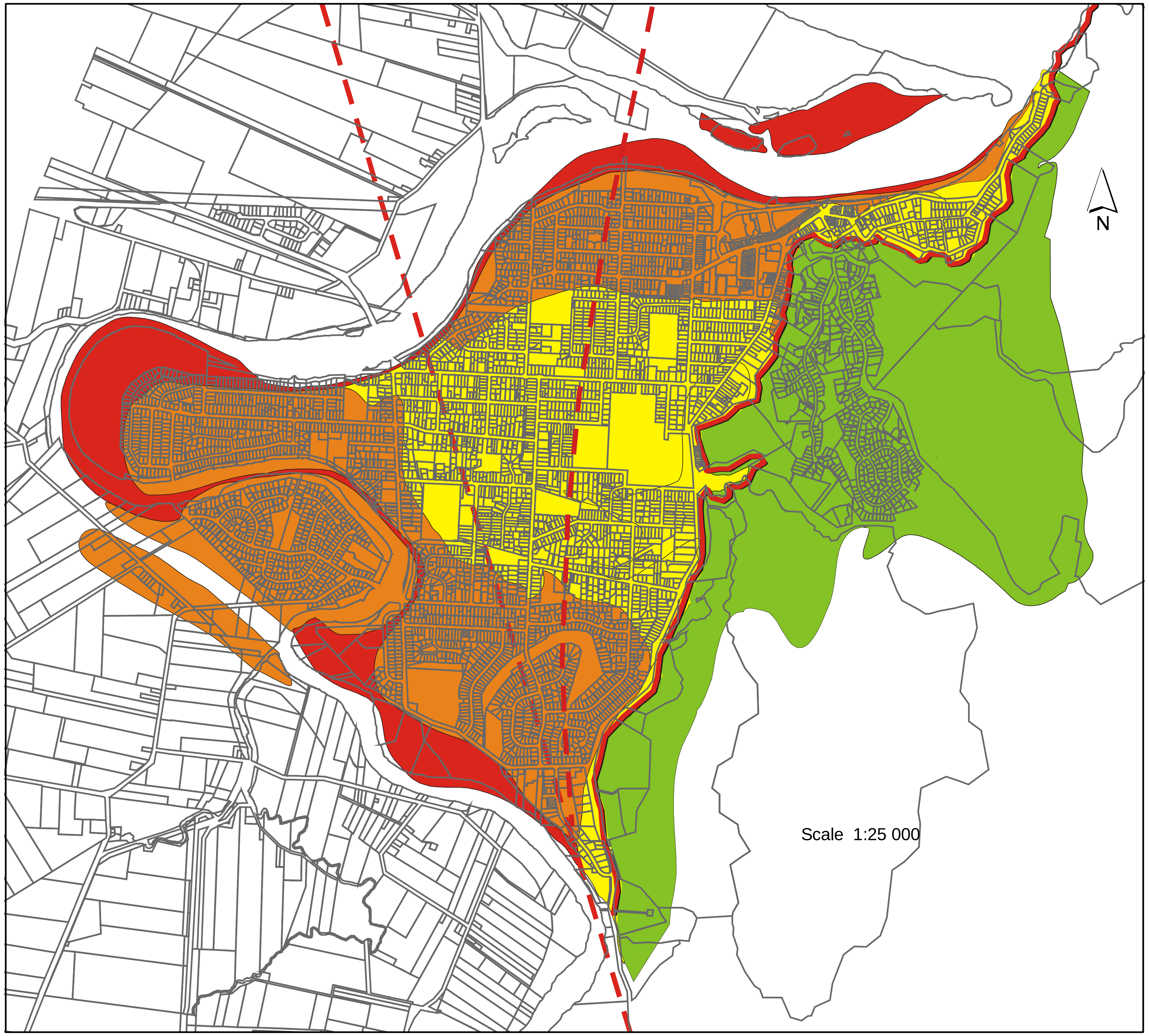


FIGURE:	Figure 4.4
PROJECT:	Whakatane Microzoning
TITLE:	Liquefaction and ground damage susceptibility map for the Whakatane Urban area.
DATE:	January 2004
DRAFTED BY:	J. Hoverd
PROJECT NO.:	430W1029
CR:	
EXPLANATION:	Ground damage excludes landslides which are dealt with separately on Figure 4.5.. Base Map: Whakatane District cadastral data.

LEGEND

Liquefaction susceptibility

🟩	Negligible
🟨	Low to Moderate MM 9 - 10
🟧	High MM 8
🟥	Very high MM 7
	NB: See text for explaination
—	Base of former coastal cliff
- - -	Estimated location of fault

Table 4.7 Descriptions of expected liquefaction ground damage for different liquefaction damage classes.

Liquefaction Damage Class	Description of expected damage
0	*No liquefaction damage is expected.*
1	*A few sand boils and minor fissures. Estimate up to 10% of total area may be affected.*
2	*Sand boils and moderate fissuring – more extensive near basin edges and in waterlogged areas: banks of rivers broken up, and embankments slumped. Settlements of up to 0.2 m. Estimate 10-20% of total area affected.*
3	*Lateral spreading common, with many fissures in alluvium (some large), slumping and fissuring of stopbanks, common sand boils. Settlements of up to 0.5 m. Estimate 20-50% of total area affected.*
4	*Lateral spreading widespread, with extensive fissures and horizontal (and some vertical) displacements of up to 10 m common especially near channel edges. Settlement of fills by up to 1.0m. Estimate >50% of total area affected.*

Table 4.8 Liquefaction Damage Classes assigned to different susceptibility ratings at different MM shaking intensities (see Table 4-7 for descriptions of liquefaction damage classes).

Liquefaction Susceptibility Rating	**MM Intensity**				
	MM6	MM7	MM8	MM9	MM10
Very high	0	1	2	3	4
High	0	0	1	2	3
Moderate	0	0	0	1	2
Low	0	0	0	0	1
Negligible	0	0	0	0	0

The resulting liquefaction susceptibility map has been prepared using CPT data and historical liquefaction information (Figure 4.4). As all areas have not been shaken over the full range of intensities during historical earthquakes, the liquefaction susceptibility ratings are extrapolated by comparing the known historical liquefaction occurrence in different soil units and their associated geotechnical properties and assigning the same susceptibility ranking to similar soil units elsewhere.

The area mapped in Whakatane as having a moderate susceptibility to liquefaction (Figure 4.4) may show minor signs classical liquefaction as well as significant ground damage during very strong MM9 to 10 intensity shaking Based on experience at Edgecumbe during the 1987 earthquake, ground damage due to the soft or weak layer underlying Whakatane will include inelastic deformation of the weak soil layer. The ground damage likely to result in these areas includes damage to brittle underground pipe networks, buckling of roads, footpaths, curb and channel and settlement of overlying fills due to the strong MM9 to 10 shaking. Shaking less than this intensity is expected to cause only minor ground surface damage although the sub-surface ground strains may be sufficient to cause fractures and damage to brittle pipe networks.

4.7 Landslide susceptibility map

Landslides are a potential hazard during strong earthquake shaking. During historical earthquakes in New Zealand landslides have often been a significant component of ground damage (Hancox et al, 1997). It has been shown that a shaking intensity of MM7 is the threshold for significant landsliding (Hancox et al, 2002) although isolated instances of landslides at lower MM shaking intensities have occurred. At MM7 the expected landslides are mainly small rock and soil falls from the most susceptible slopes. As the shaking intensity increases the magnitude and density of landsliding generally increases.

The area that is susceptible to landsliding is the eastern part of Whakatane located on or immediately below the hills. Historically the strongest earthquake shaking the Whakatane hills have been subject to is MM7 during the 1987 Edgecumbe earthquake. During this event no damaging landslides were reported in Whakatane, indicating that at least MM8 is required to generate landslides in Whakatane and the threshold may be higher.

To generate a landslide hazard map, the hilly area of Whakatane has been subdivided on the basis of slope angle. The map shows three hazard zones – none, low and moderate (Figure 4.5). The three hazard zones have been determined on the basis of landslide damage in the 1987 Edgecumbe Earthquake and the recurrence interval of strong shaking. It is recognized that much more significant landslide damage is likely during the MM 9 and 10 intensity shaking caused by rupture of the Whakatane Fault through the town. The three zones are described below:

None – the alluvial floodplains of the Whakatane River away from the base of the former coastal cliff

Low – the undulating surface of the hills

Moderate - the steep old cliffs and the colluvium wedge at the base, the run-out zone. Figure 4.7 shows the slope angle of the old cliffs behind Whakatane at various points with a natural scale and Figure 4.6 shows extended profile J, with 5 times vertical exaggeration to show the weak sand and silt soil overlying dense sand .

The locations of these cross-sections are shown on Figure A3-1. The profiles at natural scale show that the cliffs are generally at a relatively stable slope angle of 40° to 45° (or less), which is close to the angle of friction for greywacke rock scree.

The landslide risk can not be accurately quantified. However, during the Edgecumbe earthquake of 1987 there were no reports of significant rockfalls or other landslides from the steepest parts of the cliffs, indicating that very strong shaking, such as that generated by the Whakatane Fault earthquake is likely to be required to generate rockfalls and landslides from these (cliff) slopes. The soils in the low hazard zone may be more susceptible to rainstorm induced landslides than seismically induced landslides, based on comments by Pullar (1978).

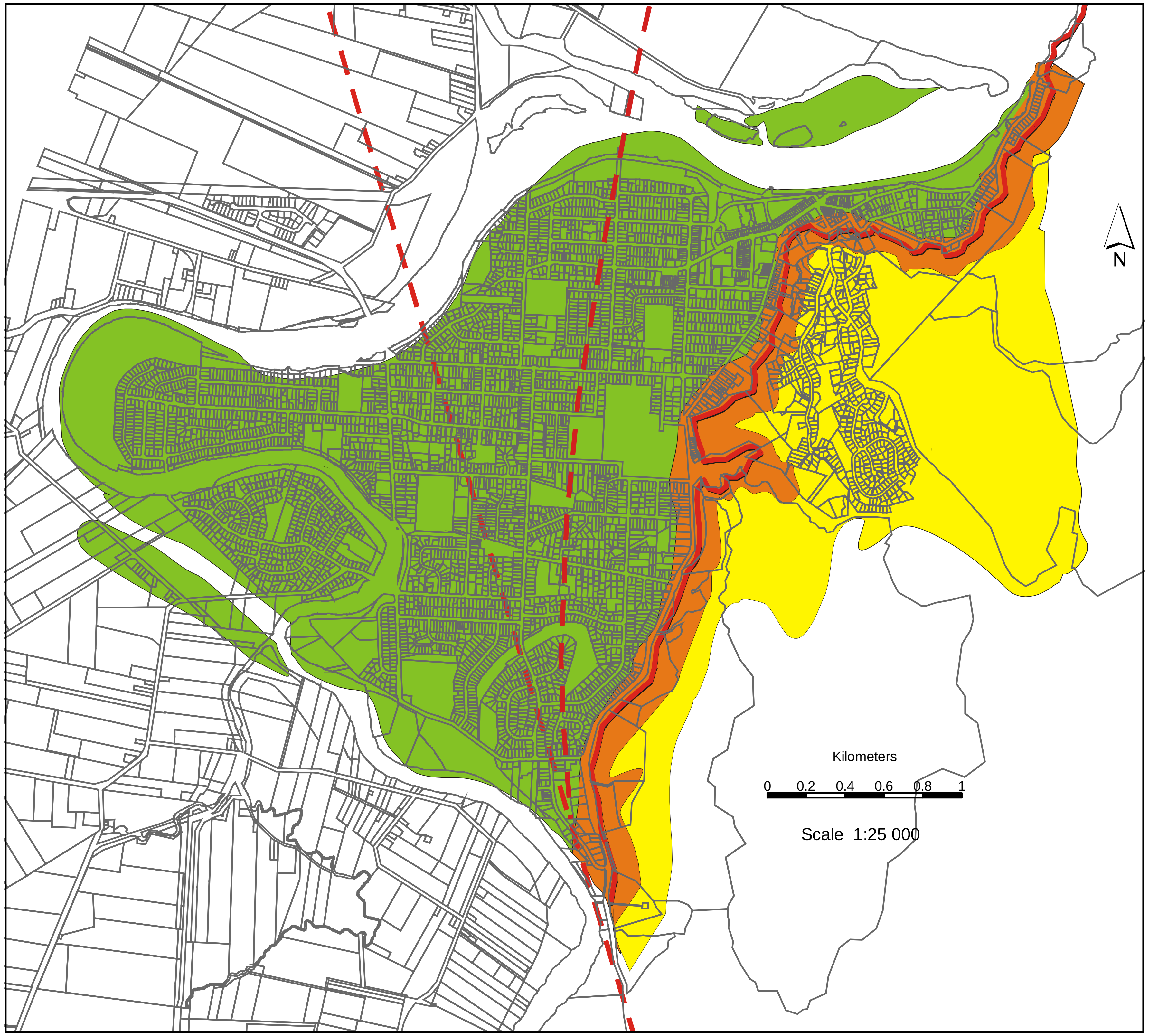


FIGURE:	Figure 4.5
PROJECT:	Whakatane Microzoning
TITLE:	Landslide hazard map for the Whakatane urban area
DATE:	January 2004
DRAFTED BY:	J. Hoverd
PROJECT NO.:	430W1029
CR:	
EXPLANATION:	Base Map: Whakatane District cadastral data.
LEGEND	Landslide Hazard 🟧 Moderate 🟨 Low 🟩 None NB: See text for explaination ━ Base of former coastal cliff ╍ Estimated location of fault

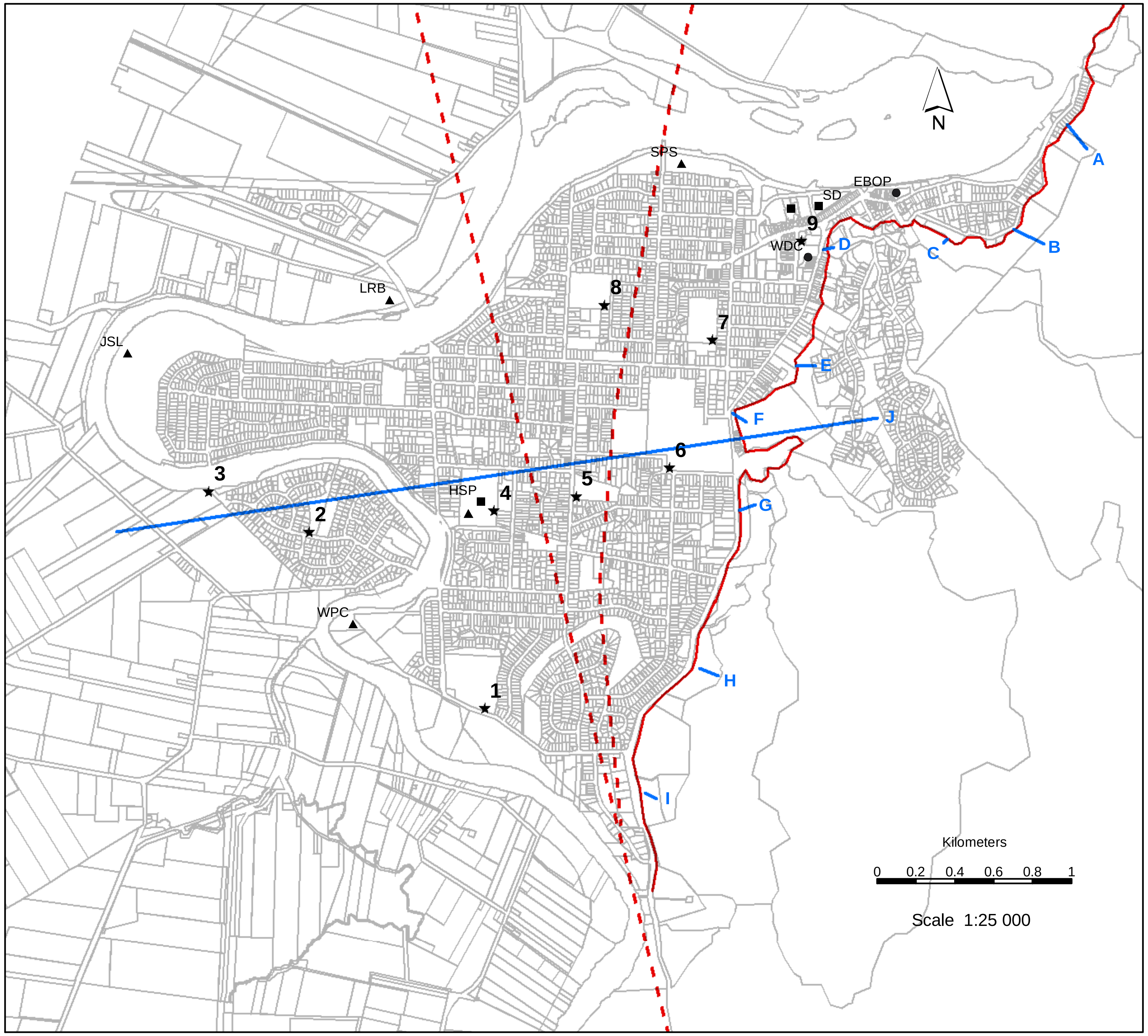


FIGURE:	A 3 - 1
PROJECT:	Whakatane Microzoning
TITLE:	CPT/SCPT locations from this report and previous investigations.
DATE:	January 2004
DRAFTED BY:	J. Hoverd
PROJECT NO.:	430W1029
CR:	
EXPLANATION:	Data sources as per Table 4.2. Base Map: Whakatane District cadastral data.
LEGEND	— profiles ▲ CPT Christensen (1995) ● CPT Other sources ■ CPT Tonkin & Taylor (various reports) ★ SCPT test site (this report) — Base of former coastal cliff - - - Estimated fault location

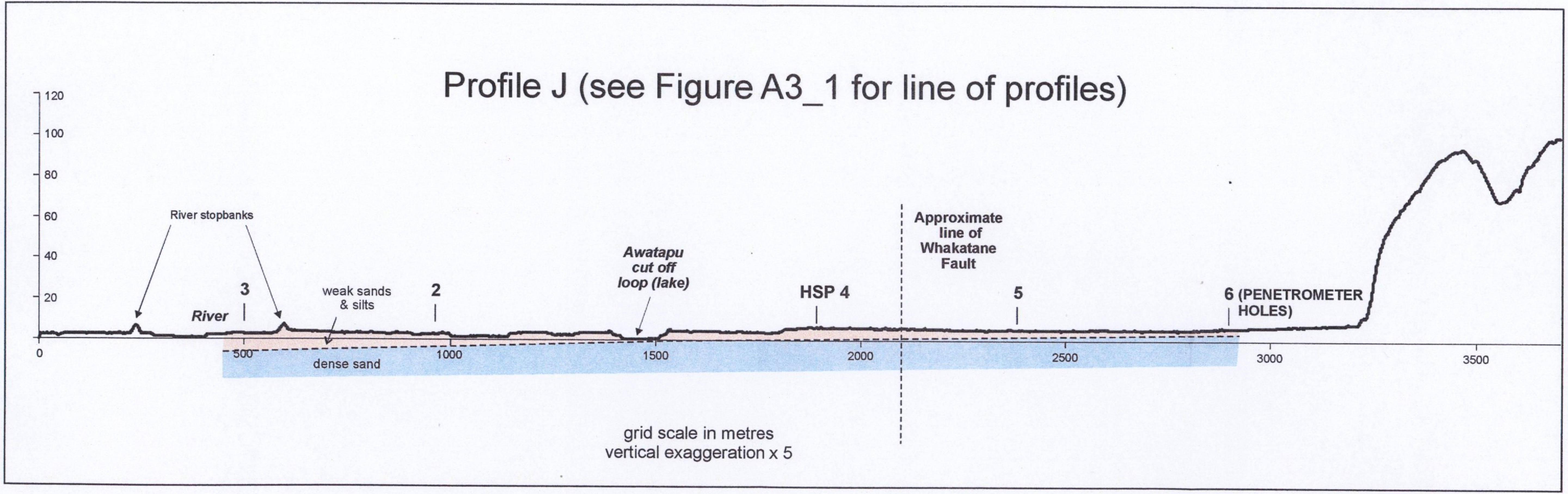
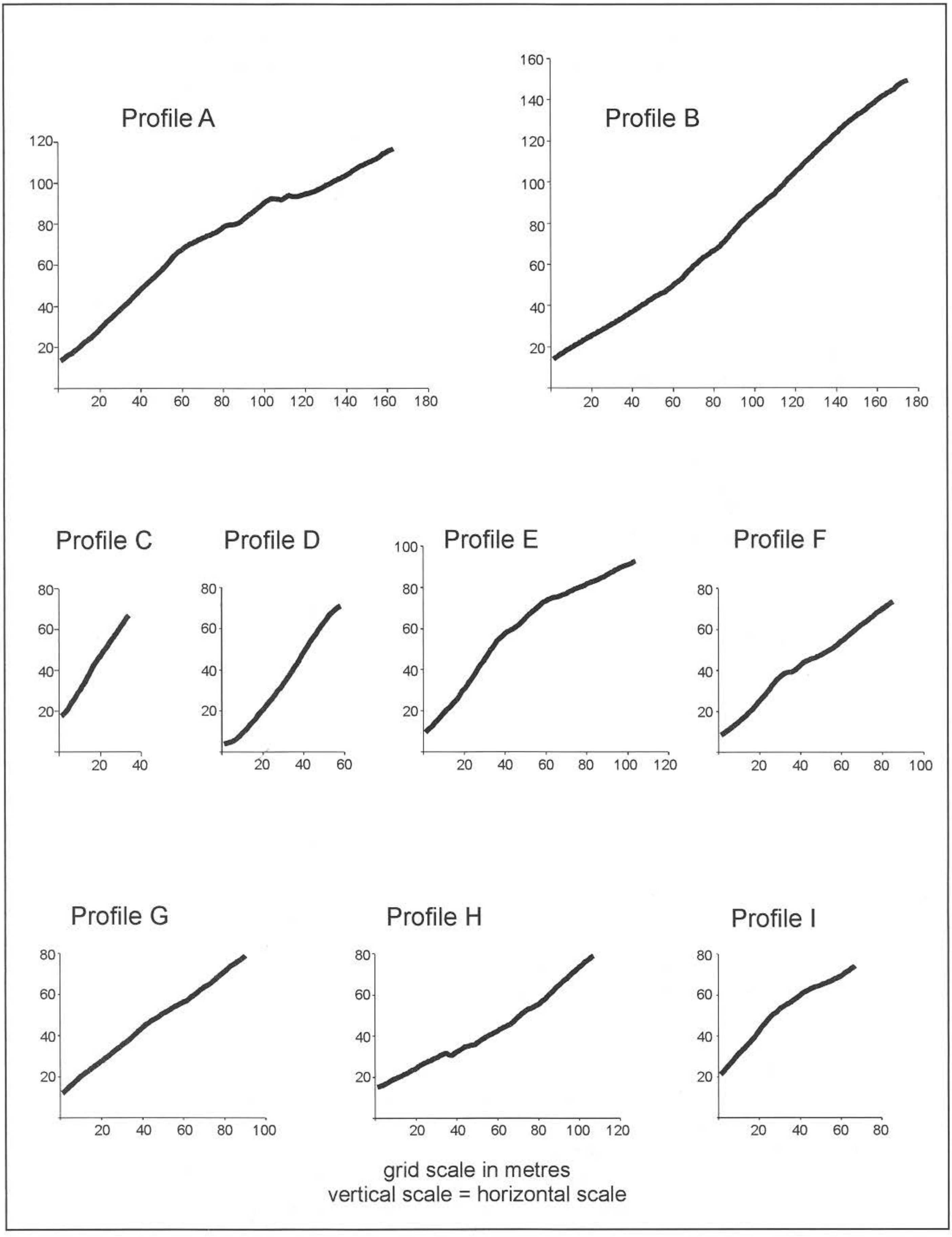

Profile J (see Figure A3_1 for line of profiles)
120
100
80
60
40
20
0
River stopbanks
River
3
weak sands & silts
2
Awatapu cut off loop (lake)
HSP 4
Approximate line of Whakatane Fault
5
6 (PENETROMETER HOLES)
500
1000
1500
2000
2500
3000
3500
dense sand
grid scale in metres
vertical exaggeration x 5

Figure 4.6



grid scale in metres
vertical scale = horizontal scale

Figure 4.7

5.0 PROBABILISTIC SEISMIC HAZARD ANALYSIS AND DESIGN SPECTRA

The probabilistic seismic hazard analysis (PSHA) method is commonly used to estimate earthquake ground motions for regions and sites. The method considers the probability that specified levels of ground motion will occur for specified time periods. The algorithm we use is the same as that used in the New Zealand seismic hazard model (Stirling *et al.* 2000, 2002); the following summarizes the major steps:

1. Determine the frequency of occurrence of earthquakes for both distributed seismicity sources and planar (fault) seismic sources based on:
   - the current understanding of the geologic/tectonic provinces in the region, including the location and activity rate of known faults;
   - the long-term historical and instrumental record of earthquakes in a broad region surrounding the site;
2. Select attenuation functions that describe the source-to-site attenuation of earthquake ground shaking on various site classes in the region, derived, if possible, from records from regions of similar tectonic setting.
3. Develop hazard spectra for the site that show expected spectral acceleration for a 5% damped oscillator over a range of periods from all possible earthquakes. The hazard spectrum is used to estimate building response given the modelled sources.

The sections below describe the major inputs to developing the PSHA model for the Whakatane microzonation study.

5.1 Earthquake sources

The earthquake source models used as the basis of this study are those of the national seismic hazard model developed by Stirling *et al.* (2000, 2002). We model earthquake sources of two types: (1) fault sources; (2) and distributed seismicity sources.

5.1.1 Fault sources

The most important earthquake source in this study is the Whakatane fault which passes directly through the study area. The parameters for the Whakatane fault including more recent information than available in the national hazard model and described elsewhere in this report are given in Table 1.

Table 5.1 Whakatane fault parameters

Fault	Fault type	Depth Max	Depth Min	Displacement (m)	Mmax	Recurrence interval (yr)	Dip
Whakatane	Strike-slip & normal	15.0	0.0	3.5	7.4	1600	90^o

5.1.2 Distributed seismicity sources

We use the historical catalogue of New Zealand earthquakes to model the occurrence of moderate-to-large (M~5 up to some maximum cutoff magnitude) "distributed" earthquakes both on and away from the major faults. We must consider distributed earthquakes to account for the large percentage of earthquakes in the historical record have that not occurred directly on mapped faults.

We apply a methodology developed from that of Frankel (1995) and Stirling *et al*. (1998, 2002) to characterise the PSH from distributed earthquakes. We use the spatial distribution of New Zealand seismicity recorded or documented since 1840 (recorded instrumentally since 1940) to estimate the likely locations and recurrence rates of distributed earthquakes at a gridwork of point sources across and beneath an area of 200 km radius around the site. The selection of the lower-bound magnitude of 5.25 is consistent with the values used in the development of both the current New Zealand Loadings Standard NZS 4203:1992 (Matuschka *et al*., 1985) and the draft Australia/New Zealand Standard (Standards Australia/Standards New Zealand. 2002). Using a lower-bound magnitude of 5.25 rather than the U.S. practice of 5.0 is required because the McVerry *et al* (2000) attenuation model used in the NSHM produces unusually high response spectrum accelerations around the spectral peaks in the 0.1-0.3 sec range at short distances for M<5.25.

Our methodology for the treatment of distributed seismicity is an improvement over the commonly used approach in PSHA of defining large area source zones over a region and uniformly distributing the seismicity recorded inside each source across the source. This is because our methodology preserves the smooth transitions in seismicity rates within the region and does not "average out" areas of significantly different seismicity rates.

5.2 Attenuation model

The attenuation model used is the New Zealand model of McVerry *et al*. (2000). This model has been used in the hazard studies defining the New Zealand hazard maps and spectral shapes in the draft Australia/New Zealand Loadings Standard AS/NZS1170.4 (Standards Australia and Standards New Zealand 2002). The McVerry *et al*. attenuation model accounts for the different tectonic regimes (i.e. crustal, subduction interface, and intraslab earthquakes in the dipping slab). It was developed mainly from New Zealand strong-motion earthquake records, but additionally contains supplementary data from elsewhere to obtain near-source constraint. This was achieved through introducing additional records at distances of less than 10 km, a distance range for which there are no New Zealand data.

The attenuation relation has been derived by modifying models from other parts of the world to obtain better fits to the supplemented New Zealand database. The crustal model was modified from the Abrahamson & Silva (1997) model that was derived from mainly western US data, while the subduction zone expression was modified from the Youngs *et al*. (1997) expression derived from subduction zone earthquakes around the world.

5.3 Hazard analysis results: 475 & 2500 year return periods

Due to the limited area covered by the study, spatial differences in hazard are negligible; therefore hazard spectra for a single site are presented rather than a suite of hazard maps covering the entire region. All hazard spectra we present are for the location: 176° 59’, 37° 58’.

The 475 year return period PSHA spectra for each soil class are shown in Figure 5.1 with the 2500 year return period spectra shown in Figure 5.2. For each soil class (soft rock; shallow soil; and deep soil) a design envelope was developed which largely contains the probabilistic spectra. Each spectrum comprises three segments described by curves with the parameters presented in Table 5.3 (475 year return period) and Table 5.5 (2500 year return period). Actual spectral values corresponding to the design envelope are show in Table 5.2 (475 year return period) and Table 5.4 (2500 year return period). The constant acceleration plateau is consistent with the approach used to derive the design spectra within the draft earthquake loading standard, AS/NZS 1170.4. The period width of this plateau and the declining leg have been varied to more appropriately reflect the site-specific study results established from the probabilistic hazard study. The declining leg function for the three site classes takes the 1/T (constant velocity) relationship commonly applied within overseas relationships. Thus the adjusted values remain within accepted norms, while retaining the expected characteristics associated with the soil classes identified.

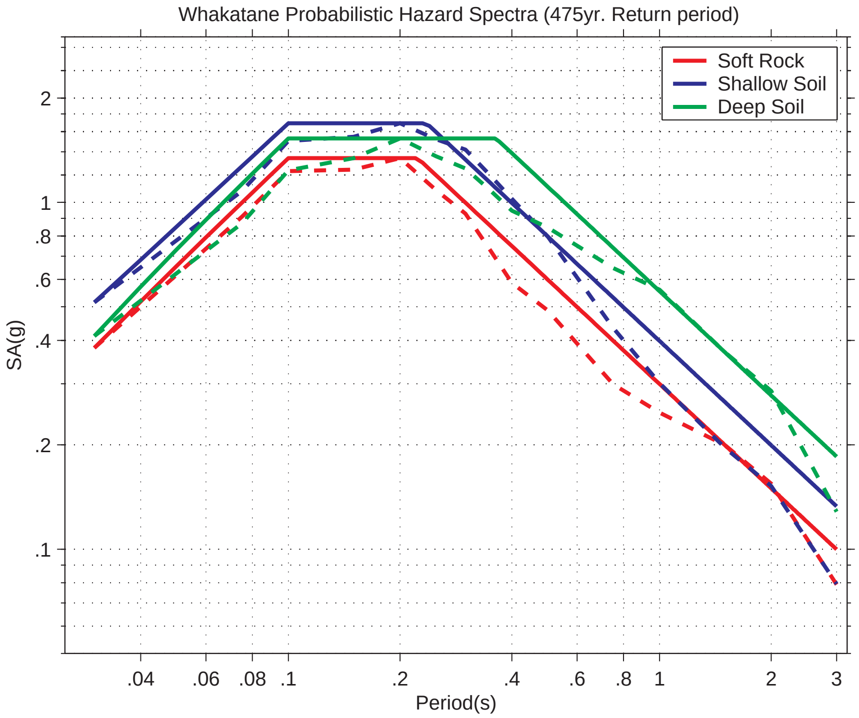


Figure 5.1 475 year return period PSHA spectra for three site classes: soft rock; shallow soil; and deep soil. The dashed lines represent the actual calculated spectral values and the solid lines correspond to the design envelope as shown in Tables 5.1 and 5.2.

Table 5.2 475 year return period PSHA spectral acceleration values

Period(s)	0.000	0.075	0.100	0.150	0.200	0.250	0.300	0.350
Shallow Soil SA(g)	.51	1.34	1.69	1.69	1.69	1.59	1.33	1.14
Deep Soil SA(g)	.41	1.21	1.53	1.53	1.53	1.53	1.53	1.53
Weak Rock SA(g)	.38	1.07	1.34	1.34	1.34	1.20	1.00	.86

Period(s)	0.400	0.500	0.750	1.000	1.500	2.000	3.000
Shallow Soil SA(g)	1.00	.80	.53	.40	.27	.20	.13
Deep Soil SA(g)	1.39	1.11	.74	.55	.37	.28	.18
Weak Rock SA(g)	.75	.60	.40	.30	.20	.15	.10

Table 5.3 Recommended spectral parameters: 475 year return period

Soil Class	T_1 (s)	T_2 (s)	Sa(0) (g)	Sa(T) for $T_1<T<T_2$ (g)	Sa(T) for $T>T_2$ (g)
B	0.1	0.22	0.38	Sa(.2) = 1.34	1.5(Sa(1.5))/T
C	0.1	0.23	0.51	Sa(.2) = 1.69	.5(Sa(.5))/T
D	0.1	0.36	0.41	Sa(.2) = 1.53	1.5(Sa(1.5))/T

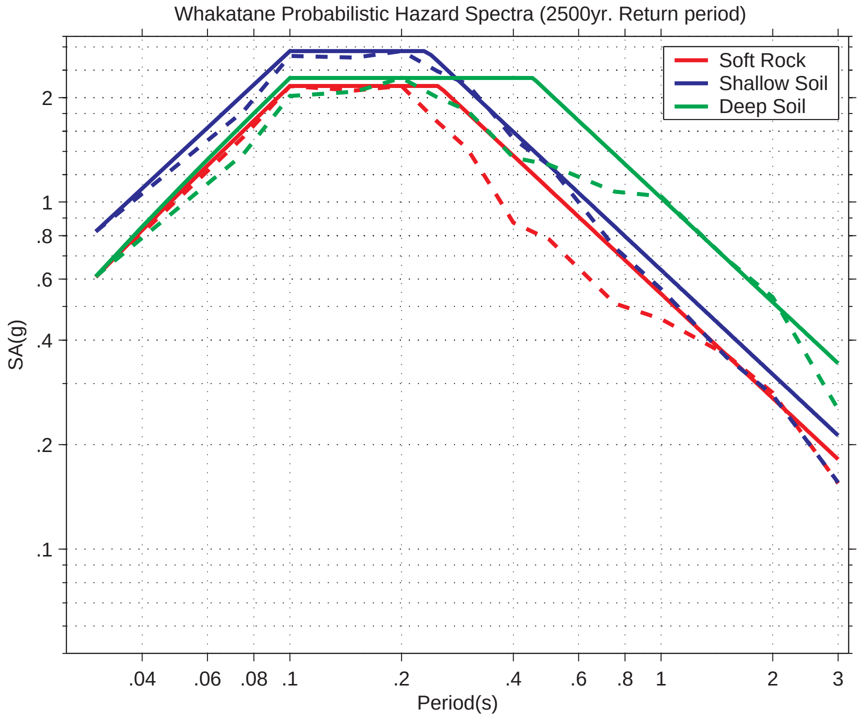


Figure 5.2 2500 year return period PSHA spectra for three site classes: soft rock; shallow soil; and deep soil. The dashed lines represent the actual calculated spectral values and the solid lines correspond to the design envelope as shown in Tables 3 and 4.

Table 5.4 2500 year return period PSHA spectral acceleration values

Period(s)	0.000	0.075	0.100	0.150	0.200	0.250	0.300	0.350
Shallow Soil SA(g)	.82	2.18	2.72	2.72	2.72	2.55	2.12	1.82
Deep Soil SA(g)	.61	1.80	2.28	2.28	2.28	2.28	2.28	2.28
Weak Rock SA(g)	.61	1.71	2.16	2.16	2.16	2.16	1.81	1.55

Period(s)	0.400	0.500	0.750	1.000	1.500	2.000	3.000
Shallow Soil SA(g)	1.36	1.09	.73	.54	.36	.27	.18
Deep Soil SA(g)	2.28	2.06	1.37	1.03	.69	.51	.34
Weak Rock SA(g)	1.59	1.28	.85	.64	.43	.32	.21

Table 5.5 Recommended spectral parameters: 2500 year return period

Soil Class	T_1 (s)	T_2 (s)	Sa(0) (g)	Sa(T) for $T_1<T<T_2$ (g)	Sa(T) for $T>T_2$ (g)
B	0.1	0.26	0.61	Sa(.2) = 2.16	1.5(Sa(1.5))/T
C	0.1	0.24	0.82	Sa(.2) = 2.72	.5(Sa(.5))/T
D	0.1	0.46	0.61	Sa(.2) = 2.28	1.5(Sa(1.5))/T

5.4 Uncertainties in the source parameters of the national seismic hazard model

There are a number of issues surrounding the use of the national seismic hazard model in site-specific studies. Firstly, the fault source parameters used in the national model are *preferred* or *mean* values that do not incorporate uncertainties. Any seismic hazard calculation should preferably take these uncertainties into account. Secondly, the area source zonation scheme of the national seismic hazard model is a relatively coarse subdivision of New Zealand, but is appropriate for the reliable determination of the seismicity parameters for each zone. Thirdly, the PSHA estimates are Poissonian (time-independent), and therefore do not contain any information on the elapsed time since the last earthquake on any of the faults or distributed seismicity sources.

6.0 COSTS AND CASUALTIES DUE TO EARTHQUAKES AFFECTING WHAKATANE

6.1 Introduction

Earthquake loss modelling in New Zealand is generally based on the Modified Mercalli Intensity (MMI) (see Appendix 4 for descriptions of the scale) as the measure of shaking strength. For any earthquake the MMI is estimated at a site of interest using the attenuation model of Dowrick & Rhoades (1999), usually modified as recommended by Smith (2002).

The Dowrick & Rhoades attenuation model is based on historical intensity data from 85 New Zealand earthquakes and is, therefore, a "New Zealand average" model that estimates intensities on "average" soils, i.e. firm to stiff soils. Deviations from the average can be expected on soils that are not average, like soft soils or rock. The cause is microzonation.

For intensities below MM7 to 8 the dominant microzonation phenomenon is amplification of shaking by soft or weak soils. Relative to the "average" intensity, patches of soft soils could amplify the shaking by up to about 1MM unit. Conversely, patches of very firm soils or rock could de-amplify or reduce the shaking by a similar amount. The sizes of the changes are poorly constrained by data, and even within a given soil class there is likely to be a significant random variation.

At MM8 intensity there may be some amplification, but less than at the lower intensities, and there may also be some minor damage to buildings as a result of liquefaction, landsliding, and topographic enhancement (Hancox et al, 2002). At high intensities, MM9 and above, the important phenomena are liquefaction (through lateral spread and subsidence), landsliding, and topographic enhancement. Some, but not all, of the buildings on either soft soils or steep ground could be adversely affected by one or other of the phenomena.

6.2 Microzonation loss allowances

We do not expect liquefaction or earthquake-induced landsliding to have significant impact on the urban area of Whakatane, except during an earthquake located on the Whakatane Fault where the fault passes through the town. For a Whakatane fault earthquake there is most likely to be a fault rupture scarp 2 to 3 m high through Whakatane in addition to shaking intensity in the urban area of MM10. For earthquakes on other faults there would be no fault scarp in the urban area and the intensity will be MM8 or smaller. MM7 to 8 was the intensity felt in Whakatane during the 1987 Edgecumbe Earthquake

For intensities below MM8, landslide effects are likely restricted to small rock falls on steeper (>40˚) coastal cliffs, road cuts and excavations, and small areas of minor shallow sliding. There may also be a few instances of slightly damaging liquefaction (small water and sand ejections and very minor lateral spreading) in alluvium.

At MM8 (zone) shaking there may be significant areas of shallow sliding of alluvium and small to moderate failures of cuts, road-edge fills and the cliffs. Evidence of liquefaction is likely to be common, with localised lateral spreading and settlements along the banks of the river and lakes. Such liquefaction and ground damage could cause breaks in brittle pipe networks.

In allowing for damage caused by potential liquefaction in Whakatane we assume the following:

- Buildings of 3 or more storeys are generally supported on piles that pass through the weak, liquefiable layers. As a result the buildings are resistant to liquefaction (even though in many cases pile systems may not have been specifically designed to resist liquefaction).
- The majority of houses will not be affected by liquefaction, even during the strongest shaking (MM10) likely to be experienced. Those that are affected are likely to be in areas where differential settlements and lateral spreading can take place – close to the river and the cut-off river channel lakes.
- As noted the proportion of buildings located in places likely to be affected by lateral spreading or substantial settlement is small, up to about 10% of all buildings.
- The proportion of buildings located in places likely to be affected by landsliding and topographic enhancement also is relatively small, less than 10% of all buildings.

Our study suggests that amplification might be significant for Whakatane for intensities of MM7 or less. The "amplification" could include either or both of soft-soil amplification and topographic enhancement. We note that there is only a limited amount of historical data, and there are no historical instances of the important intensities of MM8, 9 and 10.

We have no firm data for guidance as to the increased levels of damage that might result from the various microzonation phenomena. However, following some trial calculations we have adopted the increases illustrated in Table 6.1. At MM6 and MM7 the increases are those expected from shaking amplification equivalent to 0.5 of an MM intensity step. At MM8 we allow for a lesser degree of amplification than at MM6 and MM7, plus some additional damage due to landsliding and liquefaction. At MM9 and MM10 we allow for considerable additional damage due to landsliding and liquefaction, but no amplification. The increases in damage ratio are large, but as mentioned above, relatively few properties are on ground that is expected to be badly affected by microzonation phenomena.

Table 6.1 Examples of the increases applied to damage ratios to allow for microzonation phenomena. The MM intensity is that predicted by the New Zealand attenuation model for average soils (i.e. in the absence of microzonation). "Poor ground" is ground affected by one or more of the microzonation phenomena

MM Intensity	6.5	7.5	8.5	9.5	10.5
Damage ratio for average ground	0.0012	0.011	0.046	0.13	0.3
Damage ratio for poor ground	0.006	0.035	0.12	0.30	0.6
Ratio, poor/average	5	3.2	2.6	2.3	2.0

6.3 Tectonic movements

Earthquakes are sometimes accompanied by tectonic movements, which are the subsidence or uplift of large blocks of land. Areas of hundreds to thousands of square kilometres can be affected, and changes in elevation of several metres have been observed. During the 1987 Edgecumbe earthquake, for example, there was 1 to 2m subsidence of about 30% of the Rangitaiki Plain. The cost of countering the effects of the subsidence by increasing the heights of stopbanks, additional pumping, re-grading drains, was approximately equal to the cost of repairing shaking damage to the flood protection structures.

We expect that Whakatane will be affected by significant tectonic movements only in a future earthquake on the Whakatane Fault. During this event relative down-warping subsidence of some 2 to 3 m is expected to occur on the western side of the fault, resulting in an increased hazard from flooding in the down-warped area.

6.4 Earthquake loss calculation

The potential earthquake loss to Whakatane is obtained from:

$$\text{Loss} = \Sigma \ (D_{r,i} \ \text{x} \ \text{Replacement Value}_i),$$

where $\mathbf{D_{r,i}}$ is the vulnerability function for asset item “i”. The vulnerability function we use is the “Damage Ratio”, which is a function of the intensity of shaking and is given by:

$$D_r = \frac{\text{cost of material damage to property at risk}}{\text{replacement value of property at risk}}$$

Most of the basic mean damage ratios used in this study were derived using, as a starting point, those estimated in recent studies of New Zealand earthquakes, i.e. Edgecumbe, 1987, Hawke's Bay, 1931 and Inangahua, 1968. Domestic property damage has been studied for all three earthquakes (Dowrick 1991, Dowrick et al 1995, 2001), while non-domestic property damage has been studied for the Edgecumbe earthquake only (Dowrick & Rhoades, 1993).

For guidance in estimating mean damage ratios for building types not represented in the New Zealand datasets we rely on a set of subjective estimates made for Californian buildings (Rojahn et al, 1985). The relative vulnerabilities of the various types of non-domestic building, based on the New Zealand and Californian experiences, are listed in Table 6.2.

Table 6.2 Relative vulnerabilities assigned to various categories of non-domestic buildings.

Construction Type	Age	Height	Relative Vulnerability
Concrete Shear Wall, Concrete Block	Pre 1980	1 storey 2-3 stories 4+ stories	0.6 1.2 1.5
	1980 onwards	1 storey 2-3 stories 4+ stories	0.3 0.6 0.6
Reinforced Concrete Frame, Steel Frame	Pre 1970	1 storey 2-3 stories 4+ stories	0.8 1.5 1.9
	1970 – 1979	1 storey 2-3 stories 4+ stories	0.6 1.3 1.5
	1980 onwards	1 storey 2-3 stories 4+ stories	0.3 0.6 0.6
Tilt-up	All ages	1 storey	0.8
Timber Frame	Pre 1980	1 storey 2+ stories	0.6 0.9
	1980 onwards	1 storey 2+ stories	0.3 0.6
Earthquake Prone Building	All ages	1 storey 2+ stories	2.4 3.1
Strengthened Earthquake Prone Building	All ages	1 storey 2+ stories	1.2 1.6
“Average” Whakatane building	-	-	1.0

For modelling purposes the mean damage ratio is expressed as a smooth function of shaking intensity as follows:

$$\overline{D_r} = A \times 10^{\left(\frac{B}{MMI - C}\right)}$$

where A, B and C are constants. Examples of the functions used for estimating potential earthquake losses in Whakatane are given in Figure 6.1.

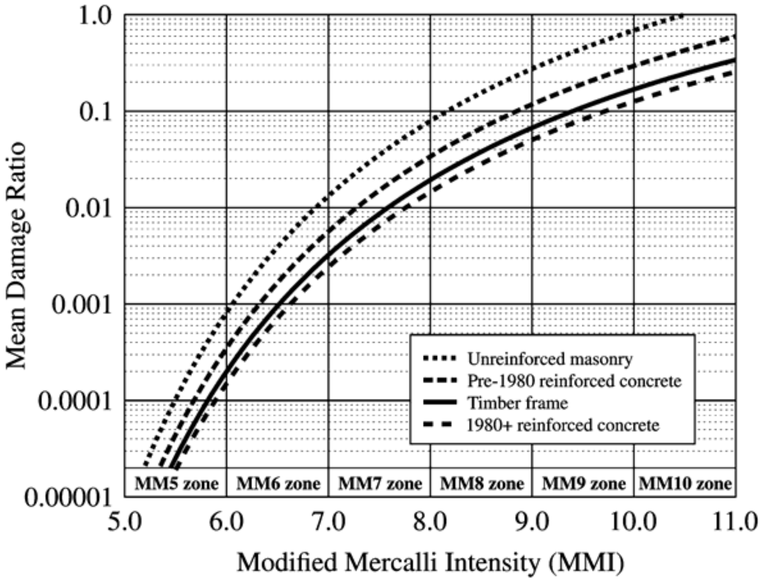


Figure 6.1 Representative mean damage ratios for typical types of buildings average ground.

6.5 Collapse of buildings and casualties

Buildings may suffer varying degrees of collapse during earthquake shaking. From the point of view of casualties it is the loss of volume after collapse that is the critical factor, with a volume loss of 50% being the level at which significant numbers of casualties begin to occur (Spence et al, 1998).

New Zealand data on collapse are very limited. Only one earthquake, the magnitude 7.8 Hawke’s Bay earthquake of 1931, has resulted in significant numbers of collapsed buildings. Dowrick (1998a,b) has categorised the damage states of approximately 330 of Napier and Hastings’ concrete and unreinforced masonry buildings. Most could be regarded as earthquake risk. About half collapsed to some degree, but only about 15% suffered volume losses of 50% or more. About 240 people were killed as a result. Of the 97 reinforced masonry or concrete buildings only 7 collapsed either partly or completely.

Previous studies of casualties in major earthquakes affecting the Wellington region (e.g. Spence et al, 1998) have combined New Zealand and overseas data to produce mean collapse rates for the various classes of building present in Wellington. Similar collapse rates are used for the loss model, expressed in the form

$$\overline{C_r} = A \times 10^{\left(\frac{B}{MMI - C}\right)}$$

where $\overline{C_r}$ is the mean collapse rate, MMI the shaking intensity, and A, B and C are constants (Figure 6.2).

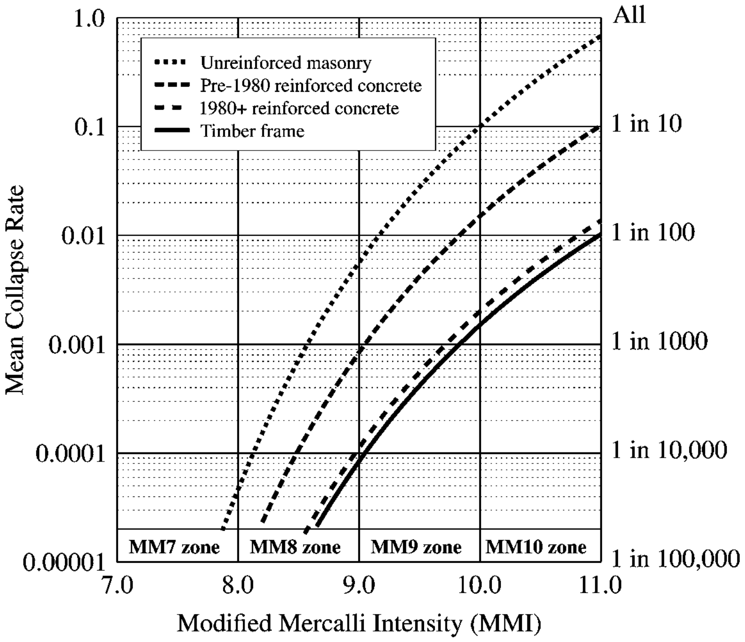


Figure 6.2 Representative mean collapse rates for typical types of building on average ground.

When a building collapses some of the occupants are killed, some are seriously injured, some are moderately injured, and the remainder are either lightly injured or uninjured. A serious injury is defined as one that will cause death if the person does not receive prompt medical or surgical treatment. A moderate injury is one that requires medical or surgical treatment but which is not immediately life threatening (e.g. a fractured limb), and light injuries are those that can be dealt with by first-aiders.

Buildings that straddle a surface-rupturing fault are likely to be severely damaged when it ruptures. The effect is highly localised, however, and there are few places in New Zealand where it is likely to contribute significantly to damage and casualties. The most important are Wellington, Lower Hutt and Petone (all bisected by the southernmost segment of the Wellington fault), Porirua (bisected by the Ohariu fault), and Whakatane (bisected by the Whakatane fault). Only a few casualties are expected to result directly from rupture of the Whakatane fault, primarily because not many buildings are likely to straddle a future rupture, and those that do are likely to be mainly light, timber framed houses that are highly resistant to collapse.

Earthquake related deaths and injuries also arise from other causes such as fire, landslide, collapsed bridges, falling glass, and panic reaction. Dowrick (in Spence et al, 1998) estimated numbers of casualties from many such causes for a large earthquake affecting the Wellington region. Those estimates, expressed as proportions of the casualties due to building collapse, are used in estimation of casualties from earthquakes affecting Whakatane.

6.6 Property data

Specific, detailed property information for Whakatane has not been used in this report. Rather we have relied on data from other centres which are expected to be similar to Whakatane.

6.7 Estimated earthquake losses

A first-order earthquake loss model for all of New Zealand has recently been developed (Cousins 2004). It enables shaking damage to buildings and casualties to be estimated for earthquakes anywhere in New Zealand. Application of the model to major earthquakes affecting Whakatane gives the losses and casualties listed in Tables 6.3 and 6.4.

Table 6.3 Losses due to Magnitude 7.4 Earthquake on the Whakatane Fault.

Magnitude 7.4 Earthquake on the Whakatane Fault		Bay of Plenty Region	Whakatane	Ohope
Damage to Housing ($millions)		200 – 500	90 – 200	40 – 70
Damage to Other Buildings ($millions)		200 – 300	40 – 90	2 – 4
Daytime Earthquake	Dead	4 – 40	1 – 20	1 – 6
	Seriously Injured	2 – 10	1 – 7	0 – 2
	Moderately Injured	5 – 50	3 – 30	1 – 7
Night-time Earthquake	Dead	1 – 5	0 – 3	0 – 1
	Seriously Injured	6 – 9	6 – 7	0
	Moderately Injured	9 – 30	7 – 20	0 – 4

Table 6.4 Losses due to Magnitude 6.5 Earthquake on the Edgecumbe Fault

Magnitude 6.5 Earthquake on the Edgecumbe Fault		Bay of Plenty Region	Whakatane	Kawerau	Edgecumbe
Damage to Housing ($millions)		90	20	20	10
Damage to Other Buildings ($millions)		80	9	10	20
Daytime Earthquake	Dead	1	0	0	1
	Seriously Injured	0	0	0	0
	Moderately Injured	1	0	0	1
Night-time Earthquake	Dead	0	0	0	0
	Seriously Injured	0	0	0	0
	Moderately Injured	0	0	0	0

7.0 CONCLUSIONS & RECOMMENDATIONS

7.1 Conclusions

1. A detailed microzoning study of the Whakatane urban area has been made. The study has involved the review of available data and the collection of new data on the geology, the faulting and the earthquake response properties of soils in the urban area.
2. A detailed geological map of the Whakatane urban area has been prepared using both the existing and new data (Figure 2.4).
3. With its location at a river mouth, the town of Whakatane is situated mainly on a river plain at the foot of an old sea cliff. The river plain consists of geologically recent beach sands at shallow depth that are covered by river sands and silts. The relatively dense beach sands under the town are overlain by the weak, loose river and flood plain deposits that are several metres thick and which tend to increase gradually in thickness away from the old cliff. In places the river plain surface is covered with slightly elevated, former sand dunes.
4. The steep, old sea cliffs are formed in a hard, indurated, geologically ancient, strong but closely jointed basement rock mass known as greywacke.
5. Much younger weak rocks, also deposited in a marine environment and known as the Ohope Beds, rest unconformably on a planar greywacke surface near the top of the cliffs. The 400,000 to 500,000 year old Ohope beds are draped with layers of volcanic ash (tephras) erupted over the last few tens of thousand years from various volcanic sources in the TVZ. The Ohope Beds and tephra deposits on top of the greywacke have been eroded to form moderate to steep sided hills and valleys.
6. The Whakatane Fault trace has been mapped off-setting high terrace remnants at Pukehoko, 6 km to the south of Whakatane. North of Pukehoko and through the Whakatane urban area where the plains of the valley floor are very young and not yet displaced by a fault scarp. Here it is apparent that any previous fault scarp has been eroded away by the Whakatane River. However, marine seismic profiling by NIWA off-shore in the Bay of Plenty has located measurable offsets on many submarine faults (Appendix 1). One of these faults, the Keepa Fault, is considered to be the offshore extension of the Whakatane Fault because of its position and an offset that demonstrates recent activity. By linking the Keepa Fault with the Pukehoko fault trace, or by projecting the fault from Pukehoko along the valley margin using a straight line, approximate locations for the fault through Whakatane town have been established (Figure 2.4). It is emphasised that, as fault traces generally have some curvature and occasional small offset steps, this location for the fault through the urban area is an estimate, and the true location of the fault could be some distance within or outside the two estimated positions shown.
7. Estimates made from slip rates and geological offsets indicate that an earthquake caused by rupture of the Whakatane Fault would be likely to produce a fault scarp some 2 to 3m high through the urban area. For long-term planning it is therefore important to better locate the fault so that the fault scarp rupture hazard can be avoided.

8. Geological evidence indicates that rupture of the fault through Whakatane is most likely to result in a relative down-throw of 2 to 3m of the ground surface on the western side of the fault. The down-thrown part of Whakatane and the plains beyond would be far more susceptible to flooding from the river and would be difficult to drain. A similar sized down-throw of ~2m or less on the north-western side of the Edgecumbe Fault resulted from the 1987 earthquake.
9. An effective method for finding the position the fault could be micro-gravity profiles across the urban area. Using the average vertical movement rate of 2mm/year on the fault with the 500,000 year age for the base of the Ohope Beds, it is apparent that the greywacke surface would be offset vertically by approximately 1 km by the fault. This or a somewhat smaller degree of basement rock offset should be readily located by a micro gravity survey.
10. There are three scenario earthquakes that best describe microzoning effects in Whakatane. (**1**) The least, almost undamaging event, is a large earthquake 20 to 50 km or more away that generates MM6 intensity shaking (or less) in Whakatane. This type of earthquake occurs approximately every 10 years. It will be strongly felt in Whakatane as the weak near surface soils amplify the shaking, possibly increasing the felt intensity from MM6 to MM7, but damage should be minor and restricted to interior damage such as a few items falling from shelves. There will not be any significant liquefaction or ground damage effects at this intensity.
11. (**2**) The most damaging for Whakatane would be an earthquake on the Whakatane Fault through the town. This earthquake with associated very strong MM9 and 10 shaking in Whakatane would cause widespread liquefaction and ground damage in the town, rockfalls and landslides on the old cliffs and road cuts, a 2 to 3 m high fault scarp through the town with 2 to 3 m of ground surface down-throw on the western side of the fault scarp. There would be extensive building damage and some casualties. Although well built houses should be structurally undamaged, the inside contents will be heavily damaged, similar to houses in Edgecumbe township in the 1987 earthquake. There would be extensive damage to buried networks, especially brittle pipes. Roads and bridges into Whakatane would be impassable, possibly for some time. However, this is a rare earthquake that may occur approximately every 1,600 years. The time since the last earthquake on the Whakatane Fault is unknown at present.
12. (**3**) Lightly to moderately damaging for Whakatane is an earthquake nearby in the TVZ or on one of the closest Shear Belt faults (the Waiohau or Waimana faults – Figure 2.2). This earthquake may cause strong MM7 to MM8 intensity shaking in Whakatane, similar to the 1987 Edgecumbe Earthquake. It would cause minor ground, structural and interior damage and perhaps a few casualties and is likely to occur approximately every 100 years.
13. Cone Penetrometer (CPT) and Seismic Cone Penetrometer Testing in Whakatane shows that the moderately dense to dense former beach sands are less than 10 metres beneath the surface (shallower closer to the old cliffs). Their shear wave velocity is ~200m/s and cone resistance (qc) generally >20MPa.

14. The dense beach sands are well within reach of piles. Piling therefore appears to be a good foundation option for support of heavier buildings and to help prevent liquefaction related ground damage to houses in susceptible areas.
15. The overlying flood plain and sand dune deposits are weak/loose sands and silts with low shear wave velocity around ~100m/s (range 66 to 148m/s) and cone resistance <10MPa. Where the ground water level is high and these upper materials are saturated they have high liquefaction potential and will begin to liquefy at MM7 intensity shaking. However, in the areas of former sand dunes, such as at the Hospital, the water table is recorded as being low and the liquefaction potential is therefore lower (see Figure 4.4).
16. A survey of 53 sites in Whakatane with a sensitive seismograph has allowed the derivation of the natural period of the ground throughout the town using Nakamura analysis (Figure 4.1).
17. The sub-surface investigation have enabled us to classify the ground in Whakatane according to the new building code into “rock”, shallow or stiff soil, and deep or soft soil categories (Figure 4.3).
18. The ground damage such and liquefaction, lateral spreading and soil yielding causing permanent ground deformations, begins to occur at MM7 shaking intensity and increases in severity with increasing intensity above MM7, to reach a maximum at MM10 (see Appendix 4). Such ground damage is unlikely to cause major damage to well built houses and for larger buildings founded on piles, but could cause extensive damage to buried networks, such as brittle pipe systems.
19. The natural period of amplifying sites in Whakatane has been calculated using the Nakamura method. The method analyses seismograph records of naturally occurring ground vibrations. This work shows that the natural period of the ground decreases away from the cliffs (Figure 4.1). Within approximately 500m of the old cliffs the natural period of the ground is less than 0.6s. There is then a gradual decrease in period to the area SE of the Landing Bridge that has a natural period >3s (see Figure 4.1).
20. To avoid resonant amplification effects, the natural period of built structures should not be close to the natural period of the ground. The natural period of a single storey house is about 0.1s and a 3 storey building about 0.3 s.
21. The earthquake triggered landslide hazard in Whakatane is considered to be moderate along the old, steep sea cliffs and at their toe, in the landslide run-out zone, low in the hill suburbs and non-existent on the plains (see Figure 4.5). As well, significant, damaging landsliding would occur only in the very strong, MM9 to 10 intensity shaking caused by a Whakatane Fault earthquake. For other earthquakes that may cause MM7 to 8 intensity shaking, landslide damage is likely to be minor.
22. All known earthquake sources have been used in the NZ probabilistic Seismic hazard model to derive the 475 and 2,500 year recurrence interval earthquake design spectra for Whakatane (Figures 5.1 & 5.2). The 475 year recurrence interval spectra have a 10% probability of occurrence in 50 years and are commonly used for the design of non-critical structures, while the 2,500 year spectra are used for the design of critical structures such as bridges, hospitals and schools.

23. The design spectra are derived for each of the four (strong rock, weak rock, shallow or stiff soil, and deep or soft soil) rock and soil classes determined to be present in Whakatane (Figure 4.3)
24. Our loss estimates for the region and the town have been made for the two damaging events in conclusion points 11 and 12 above. Rupture of the Whakatane Fault will cause very heavy damage with a smaller number of casualties from a night-time event. The more frequent Edgecumbe type of earthquake the damage and casualties are aligned with what occurred in 1978.

7.2 Recommendations

- An earthquake caused by rupture of the Whakatane Fault would produce a fault scarp some 2 to 3m high through the urban area. For long-term planning it is therefore important to better locate the fault so that the fault scarp rupture hazard can be avoided.
- Several methods could be used to find the position the fault through the town. Micro-gravity profiles across the urban area can be made readily along existing roadway margins or footpaths without disrupting normal activity in the town. It is a good project that could readily be carried out by a student as a post graduate exercise. Using the average vertical movement rate of 2mm/year on the fault with the 500,000 year age for the base of the Ohope Beds, it is apparent that the greywacke surface would be offset vertically by approximately 1 km by the fault. This, or a somewhat smaller degree of basement rock offset, provides a significant density contrast on either side of the fault that should be readily located by a detailed gravity survey. As well the fault step should be readily located by other geophysical methods, such as seismic profiling. Shallow seismic profiling through the town would probably need to be carried out at night and would require road closure. In addition, seismic profiling requires a small team of trained people and a light truck load of special equipment. However, the results achieved may be a more positive or definite location for the fault than can be achieved with a detailed gravity survey. A further option would be a shallow gravity profile along the beach at Thornton for a distance of 4 to 5 km from the Whakatane River mouth.
- Our advice is to carry out the detailed gravity profiles across the estimated location of the fault scarp in the town as a first trial. Once the gravity results are obtained and reviewed a decision could be made as to whether seismic profiles, and other options such as drilling, are necessary.
- To avoid resonant amplification effects, the natural period of built structures should not be close to the natural period of the ground. The natural period of a single storey house is about 0.1s and a 3 storey building about 0.3 s.
- Long-term planning for Whakatane could include: 1) gradual replacement of brittle pipes with ductile ones and other vulnerable life-lines; 2) avoid locating of new critical facilities in the town on the downthrown side of the Whakatane Fault; 3) planning for emergency access into the town, and for recovery of the town if the Whakatane Fault does rupture.

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APPENDICES

1 NIWA Report
2 Nakamura Data
3 SCPT Data
4 MM Intensity descriptions

(See separate volume: Volume 2 Appendices)

Institute of Geological & Nuclear Sciences Limited

Gracefield Research Centre
69 Gracefield Road
PO Box 30 368
Lower Hutt
New Zealand
Phone +64-4-570 1444
Fax +64-4-570 4600

Rafter Research Centre
30 Gracefield Road
PO Box 31 312
Lower Hutt
New Zealand
Phone +64-4-570 4637
Fax +64-4-570 4657

Dunedin Research Centre
764 Cumberland Street
Private Bag 1930
Dunedin
New Zealand
Phone +64-3-477 4050
Fax +64-3-477 5232

Wairakei Research Centre
State Highway 1, Wairakei
Private Bag 2000
Taupo
New Zealand
Phone +64-7-374 8211
Fax +64-7-374 8199

For more information visit the GNS website
http://www.gns.cri.nz